PENGARUH PENAMBAHAN SERBUK GELATIN TERHADAP SIFAT MEKANIK DAN BIODEGRADABILITAS PLASTIK CAMPURAN POLITILEN TEREFTALAT BEKAS DAN PATI SAGU

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PENGARUH PENAMBAHAN SERBUK GELATIN TERHADAP SIFAT MEKANIK DAN BIODEGRADABILITAS PLASTIK CAMPURAN POLIETILEN TEREFTALAT BEKAS DAN PATI SAGU

ABSTRAK

Telah dilakukan penelitian tentang pengaruh penambahan serbuk gelatin terhadap sifat mekanik dan biodegradabilitas plastik campuran polietilen tereftalat bekas dan pati sagu. Pada penelitian ini dibuat 4 sampel dengan penambahan serbuk gelatin yang divariasikan sebanyak 0 g, 5 g, 10 g dan 15 g. Sampel tersebut dilakukan penguburan selama 10 hari, 20 hari, 30 hari dan 40 hari. Hasil penguburan kemudian dilakukan pengujian sifat mekanik seperti kuat lentur, kuat tarik dan biodegradabilitas. Hasil menunjukkan serbuk gelatin kurang mempengaruhi kekuatan lentur sampel, nilai kuat lentur tertinggi didapatkan dari sampel tanpa penambahan serbuk gelatin. Nilai kuat tarik tertinggi didapatkan dari sampel dengan penambahan serbuk gelatin sebanyak 5 g sebesar 505,411 N/mm^2. Sampel yang paling cepat terdegradasi adalah sampel plastik campuran polietilen tereftalat bekas dan pati sagu dengan penambahan serbuk gelatin sebanyak 15 g.

Kata kunci : polietilen tereftalat, pati sagu, serbuk gelatin, biodegradabel, kuat lentur dan kuat tarik

EFFECT OF ADDITION OF GELATIN POWDER ON THE`MECHANICAL PROPERTIES AND BIODEGRADABILITITY OF PLASTIC EX-POLYETYLENE TEREPHTHALATE WITH SAGO STARCH

ABSTRACT

The study on the effect of the addition of gelatin powder on the mechanical properties and biodegradability of plastic ex-polyethylene terephthalate with sago starch has been done. In this study, 4 samples were made by adding gelatin powder with variation of 0 g, 5 g, 10 g and 15 g. Sample were buried for 10 days, 20 days, 30 days and 40 days. After burying the samples, the mechanical properties such flexure strength, tensile strength and biodegradability were examined. These results indicate that the gelatin powder samples don't highly influence the flexure strength. The highest flexural strength values were obtained from the samples without the addition of gelatin powder. The highest tensile strength values were obtained from the samples with the addition of gelatin powder 5 g, 505.411 N/mm^2. The most rapidly degraded sample was resulted from mixture of plastic ex-polyethylene terephthalate and sago starch with the addition of as much as 15 g of gelatin powder.

Key word : polyethylene terephthalate, sago starch, gelatin powder, biodegradable, flexural strength and tensile strength

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Resalina

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BAB I

PENDAHULUAN

1.1 Latar Belakang

Plastik adalah senyawa makromolekul organik yang diperoleh dengan cara polimerisasi, polikondensasi, poliadisi dari monomer atau oligomer atau dengan perubahan kimiawi makromolekul alami. Penggunaan kemasan plastik tak bisa lepas dalam kehidupan sehari-hari. Hal ini dikarenakan plastik memiliki sifat unggul seperti ringan tetapi kuat, transparan, tahan air serta harganya relatif murah dan terjangkau oleh semua kalangan masyarakat.

Plastik yang digunakan saat ini merupakan polimer sintetik, terbuat dari minyak bumi (*non-renewable*) yang tidak dapat terdegradasi mikroorganisme di lingkungan. Kondisi demikian ini menyebabkan kemasan plastik sintetik tersebut tidak dapat dipertahankan penggunaannya secara meluas karena akan menambah persoalan lingkungan dan kesehatan di waktu mendatang (Latief, 2001).

Polietilen tereftalat (PET) adalah salah satu plastik yang terbuat dari minyak bumi yang banyak digunakan dalam kehidupan sehari-hari. PET yang digunakan sebagai botol plastik diproduksi milyaran ton di dunia. Seperti plastik konvensional lainnya, kesuksesan PET sebagai komoditas besar polimer menyebabkan PET menjadi permasalahan limbah utama, lebih dari 2400 milyar kg botol PET yang diproduksi di Amerika pada tahun 2006 dan hanya 23,5% yang dapat didaur ulang dan terurai di tanah. Tereftalat acid yang terkandung dalam

PET umumnya berpotensi menyimpan sintesis mikroba yang ditambahkan oleh polimer plastik biodegradabel polihidroksialkanoat (PHA).

Plastik biodegradabel (*biodegradable plastic)* adalah plastik yang dapat digunakan layaknya seperti plastik konvensional akan tetapi plastik biodegradabel terbuat dari material yang dapat diperbaharui, yaitu dari senyawa-senyawa yang terkandung pada tanaman seperti selulosa dan protein yang dapat hancur terurai oleh aktivitas mikroorganisme menjadikan hasil akhir plastik berupa air dan gas karbondioksida yang habis terpakai dan dibuang ke lingkungan. Proyeksi kebutuhan plastik biodegradabel hingga tahun 2010 yang dikeluarkan oleh *Japan Biodegradable Plastic Society*; di tahun 1999, produksi plastik biodegradabel hanya sebesar 2500 ton, yang merupakan 1/10.000 dari total produksi bahan plastik sintetik. Pada tahun 2010, diproyeksikan produksi plastik biodegradabel akan mencapai 1.200.000 ton atau menjadi 1/10 dari total produksi bahan plastik dunia. Industri plastik biodegradabel akan berkembang menjadi industri besar di masa yang akan datang (Pranamuda, 2003).

Salah satu jenis plastik biodegradabel adalah plastik berbasiskan pati. Hasil pertanian Indonesia yang potensial untuk dikembangkan menjadi biopolimer adalah jagung, sagu, kacang kedele, kentang, tepung tapioka, ubi kayu (nabati) dan kitin dari kulit udang (hewani) (Firdaus, F dan Chairil Anwar, 2004).

Indonesia merupakan pemilik areal sagu terbesar di dunia. Luas areal sagu di Indonesia sekitar 1,238 juta ha atau 51,3% dari 2,201 juta ha areal sagu di dunia disusul Papua New Guinea 43,3% (Abner L. dan Miftahorrahman, 2002). Produktivitas pati sagu kering mencapai 2 ton/ha/tahun, lebih banyak

dibandingkan ubi kayu yang hanya 1,5 ton/ha/tahun, kentang sebesar 2,5 ton/ha/tahun maupun jagung sebesar 5,5 ton/ha/tahun (Haryadi, 2004). Campuran plastik *polypropylene* pati sagu dengan kandungan 10 gr gula jagung merupakan plastik yang dapat terurai dengan cepat dengan sifat mekanik yang baik (Elvi, 2011). Penambahan pati pada material polimer memberikan efek negatif terhadap kekuatan mekanis plastik tersebut. Plastik akan bersifat rapuh dan rentan mengalami kerusakan jika diberikan beban. Solusi untuk mengatasi hal tersebut adalah dengan memberikan bahan pemlastis yang bersifat mengurangi kekakuan dari bahan polimer. Salah satu bahan alami yang dapat berfungsi sebagai pemlastis adalah gelatin.

Gelatin dan kolagen merupakan bahan polimer yang identik dengan hewan. Kolagen adalah sejenis protein tak jenuh yang mempunyai sifat kekakuan yang baik. Gelatin terbuat dari denaturasi kolagen secara fisika dan kimia. Gelatin bersifat *reversible gels*, kualitas gelatin dapat ditentukan dari kekentalannya. Gelatin dapat menjadi pemlastis yang baik untuk penambahan air dan penambahan gliserol. Penelitian yang dilakukan oleh Darni, Y. dkk., 2008 mengenai bioplastik pati pisang dan gelatin, kekuatan tarik dan Modulus Young lebih optimal bila memiliki kandungan gelatin tertinggi yakni sebesar 40% dan sedikit kandungan pati.

Melihat potensi dari material tersebut, maka dilakukan penelitian mengenai plastik kemasan PET bekas ditambahkan pati sagu sebagai material yang dapat terurai dan penambahan serbuk gelatin sebagai bahan pemlastis alami yang berguna untuk memperkuat ikatan antar monomer bahan plastik.

1.2 Tujuan Penelitian

Adapun tujuan dari penelitian ini adalah:

1) Menghasilkan plastik biodegradabel.
2) Mengetahui pengaruh penambahan serbuk gelatin terhadap kuat lentur, kuat tarik dan degradabilitas pada plastik PET bekas campuran pati sagu dan serbuk gelatin.
3) Membandingkan kuat lentur dan kuat tarik plastik PET bekas campuran pati sagu dan serbuk gelatin sebelum dan sesudah dilakukan penguburan.

1.3 Manfaat Penelitian

Diharapkan manfaat dari penelitian ini adalah:

1) Dihasilkannya plastik biodegradabel dari plastik PET bekas campuran pati sagu dan serbuk gelatin dengan sifat mekanik yang baik.
2) Masyarakat merasa aman dengan pemakaian plastik biodegradabel dalam pemenuhan kebutuhan sehari-hari.
3) Berkurangnya permasalahan lingkungan yang diakibatkan oleh material berbahan plastik, karena plastik biodegradabel dapat terurai secara alami.

1.4 Batasan Masalah

Pada penelitian ini digunakan plastik PET bekas. Parameter yang akan diamati pada penelitian ini adalah kuat lentur, kuat tarik dan biodegradabilitas yang dimiliki plastik dengan perbandingan komposisi plastik, pati sagu yang tetap, dan serbuk gelatin sapi yang divariasikan.

BAB II

LANDASAN TEORI

2.1 Plastik

Plastik adalah suatu polimer yang mempunyai sifat elastik yang dapat dicetak atau diekstruksi menjadi bentuk yang diinginkan dan mengeras setelah didinginkan atau diuapkan (Emriadi, 2005). Plastik dapat digolongkan berdasarkan kriteria berikut, yaitu:

1) Sifat fisikanya
   a. Termoplastik merupakan jenis plastik yang bisa didaur ulang atau dicetak kembali. Contoh : polietilen (PE), polistiren (PS), polikarbonat (PC).
   b. Termoset merupakan jenis plastik yang tidak bisa didaur ulang atau dicetak kembali.
2) Kinerja dan penggunaanya
   a. Plastik komoditas merupakan plastik yang mempunyai sifat mekanik tidak terlalu bagus dan tidak tahan panas.
   b. Plastik teknik merupakan plastik yang tahan panas dan sifat mekaniknya bagus.
   c. Plastik teknik khusus merupakan plastik yang mempunyai temperatur operasi di atas 150°C dan mempunyai sifat mekanik yang sangat bagus.
3) Berdasarkan tanda plastik kemasan yang telah disepakati dan biasa digunakan sebagai acuan daur ulang, plastik dibedakan menjadi :

a. *Polyethylene Terephthalate* (PET, PETE)

b. *High Density Polyethylene* (HDPE)

c. *Polyvinyl Chloride* (PVC)

d. *Low Density Polyethylene* (LDPE)

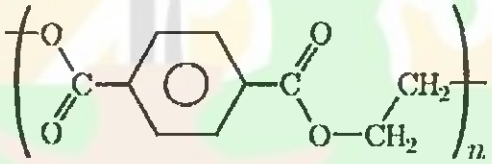
e. *Polypropylene* (PP)

f. *Polystyrene* (PS)

g. *Polycarbonate* (PC)

2.2 Polietilen Tereftalat (PET)

Polietilen Tereftalat yang sering disebut PET dibuat dari etilen glikol (EG) dan terephtalicacid (TPA) atau dimetyl ester atau asam terepthalat (DMT). Pada gambar 2.1 ditunjukkan struktur kimia polietilen tereftalat.



Gambar 2.1 Struktur kimia polietilen tereftalat
(Sumber : Wikipedia, 2011)

PET merupakan keluarga polyester seperti halnya PC. Polimer PET dapat diberi penguat *fiber glass* atau *filler mineral*. PET film bersifat jernih, kuat, liat, dimensinya stabil, tahan nyala api, tidak beracun, permeabilitas terhadap gas, aroma maupun air rendah. *PET engineer resin* mempunyai kombinasi sifat-sifat sebagai berikut, dimana kekuatannya tinggi, kaku, dimensinya stabil, tahan bahan kimia dan panas, serta mempunyai sifat elektrikal yang baik. PET memiliki daya serap uap air yang rendah, demikian juga daya serap terhadap air. PET dapat

diproses dengan proses ekstrusi pada suhu tinggi 518 °F - 608°F, selain itu juga dapat diproses dengan teknik cetak injeksi maupun cetak tiup.

2.3 Plastik Biodegradabel

Plastik biodegradabel adalah plastik yang dapat digunakan layaknya plastik konvensional, namun akan hancur terurai oleh aktivitas mikroorganisme menjadi hasil akhir air dan gas karbondioksida setelah habis terpakai dan dibuang ke lingkungan (Pranamuda, 2003). Plastik biodegradabel merupakan suatu bahan dalam kondisi dan waktu tertentu mengalami perubahan dalam struktur kimianya oleh pengaruh mikroorganisme seperti bakteri, jamur, dan alga.

Plastik biodegradabel dapat dihasilkan melalui beberapa cara, salah satunya adalah biosintesis menggunakan bahan berpati atau berselulosa. Cara pembuatan plastik biodegradabel yang berbasiskan pati antara lain:

1) Mencampur pati dengan plastik konvensional (PE atau PP) dalam jumlah kecil (10%-20%)
2) Mencampur pati dengan turunan hasil samping minyak bumi, seperti PCL, dalam komposisi yang sama (50%)
3) Menggunakan proses ekstruksi untuk mencampur pati dengan bahan-bahan seperti protein kedelai, gliserol, alginate, lignin dan sebagainya sebagai *plasticizer*.

Potensi penggunaan pati sebagai plastik biodegradabel berkisar 80% - 95% dari pasar plastik biodegradabel yang ada (Vilpoux O. and Luc Averous, 2006).

Sumber pati yang banyak digunakan antara lain sagu, jagung, ubi kayu, gandum, beras dan kentang.

2.4 Pati Sagu

Pati sagu merupakan hasil ekstraksi empulur pohon sagu (*Metroxylon sp.*) yang sudah tua (berumur 8-16) tahun. Pati sagu tersusun atas dua fraksi penting yaitu amilosa yang merupakan fraksi linier dan amilopektin yang merupakan fraksi cabang. Kandungan amilopektin pati sagu adalah 73%± 3 (Ahmad danWilliams, 1998).

Pati sagu memiliki ukuran granula rata-rata 30 μ, kadar amilosa 27%± 3, suhu gelatinisasi pati 70°C, entalpi gelatinisasi 15-17 J/g, dan termasuk tipe C pada pola *X-ray diffraction*. Sifat pati sagu berbeda dengan pati gandum. Perbandingan sifat kedua jenis pati tersebut ditunjukkan pada Tabel 2.1. Sifat amilografi pati sagu dapat dilihat pada Tabel 2.2, sedangkan komposisi kimia pati sagu ditunjukkan pada Tabel 2.3.

Tabel 2.1 Sifat Pati Sagu dan Pati Gandum

Jenis pati	Bentuk granula	Ukuran granula (μ)	Kandungan amilosa/amilopektin	Range suhu gelatinisasi (°C)
Sagu	Elips	20 – 60	27/73	60 – 72
Gandum	Elips	2 – 35	25/75	52 – 64

Sumber : Knight (1969)

Tabel 2.2 Sifat Amilografi Pati Sagu

Gelatinisasi		Granula pecah		Viskositas (BU)		
Suhu (°C)	Waktu (menit)	Suhu (°C)	Waktu (menit)	Puncak	50°C	Balik
67,5	25,00	73,50	29,00	520	480	-40

Sumber : Richana dkk. (2000)

Tabel 2.3 Komposisi Kimia Pati Sagu

Komponen	Jumlah (%)
Protein	0,62
Abu	0,32
Serat	0,15
Pati	75,88
Amilosa	23,94
Amilopektin	76,06

Sumber: Richana dkk. (2000)

Pati sagu yang telah mengalami modifikasi akan mengalami beberapa perubahan sifat dibandingkan pati alaminya. Modifikasi pati dapat dilakukan dengan mereaksikan pati dengan senyawa modifikasi (substituen) yang menyebabkan perubahan struktur sehingga sifat pati alami berubah. Gugus hidroksil pati membentuk ikatan ester dengan substituen atau pereaksi menghasilkan turunan pati. Setiap unit glukosa mengandung 3 gugus hidroksil (OH) yang sangat potensial untuk menghasilkan turunan pati yaitu pada atom C nomor 2, 3, dan 6 (Richardson, S. and Lo Gorton, 2003). Sifat pati modifikasi tergantung pada beberapa faktor seperti reaksi modifikasi, gugus pensubstitusi, derajat substitusi, dan distribusi gugus substituen. Distribusi gugus substituen pada modifikasi pati dapat terjadi pada monomer sepanjang rantai polimer, pada daerah kristalin atau amorphus, dan pada permukaan granula (Richardson, S. and Lo Gorton, 2003).

Light (1990) menjelaskan bahwa metode modifikasi pati dikategorikan menjadi dua yaitu kimia dan fisik. Modifikasi kimia dapat dilakukan melalui

proses konversi termasuk hidrolisis asam, oksidasi, dekstrinasi, dan konversi asam serta derivatisasi termasuk *crosslinking*, stabilisasi dan penambahan gugus fungsional tertentu. Proses pregelatinisasi, penyesuaian ukuran partikel dan penyesuaian kelembaban (*moisture*) merupakan metode modifikasi secara fisik.

2.5 Bahan Pemlastis

Pemlastis adalah bahan organik dengan berat molekul rendah yang ditambahkan untuk memperlemah kekakuan dari polimer, sekaligus meningkatkan fleksibilitas dan ekstensibilitas polimer (Julianti dan Nurminah, 2007). Pemlastis adalah zat aditif dengan titik didih tinggi yang dapat berupa cairan, padatan, gum sintetis atau murni alami.

Penambahan pemlastis baik sintetis maupun alami bertujuan untuk memperbaiki sifat bahan selama pembuatan plastik, memperluas atau memodifikasi sifat dasarnya atau dapat memunculkan sifat baru yang tidak ada dalam bahan dasarnya (Spink dan Waychoff dalam Frados, 1958). Penambahan pemlastis juga dapat menurunkan kekuatan ikatan hidrogen internal pada ikatan intermolekuler, meningkatkan fleksibilitas film dan menurunkan sifat *barrier* (Harahap, 2009).

2.6 Serbuk Gelatin

Gelatin adalah salah satu hidrokoloid yang dapat digunakan sebagai *gelling*, bahan pengental (*thickner*) atau penstabil. Gelatin berbeda dengan hidrokoloid lain, karena kebanyakan hidrokoloid adalah polisakarida seperti karagenan dan pektin, sedangkan gelatin merupakan protein mudah dicerna,

mengandung semua asam-asam amino essensial kecuali triptofan. Komposisi asam amino dari gelatin dapat dilihat pada Tabel 2.4.

Gelatin merupakan protein konversi bersifat larut air yang diperoleh dari hidrolisis kolagen yang bersifat tidak larut air. Tulang sapi, kulit sapi dan kulit babi adalah bahan yang biasa digunakan untuk memperoleh gelatin (Sobral, 2007).

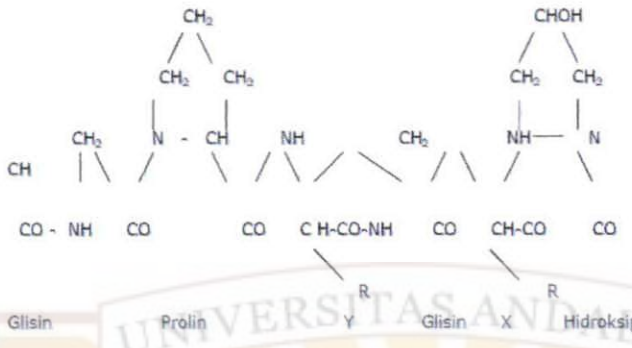
Tabel 2.4 Kandungan Asam Amino pada Gelatin

Jenis Asam Amino	Jumlah (persen)
Glisin	26,4 – 30,5
Prolin	14,0 – 18,0
Hidroksiprolin	13,3 – 14,5
Asam glutamat	11,1 – 11,7
Alanin	8,6 – 11,3

Sumber : Parker (1982) disitasi oleh Septriansyah (2000)

Ditinjau dari struktur kimianya yang merupakan polipeptida asam amino, gelatin merupakan suatu senyawa ampoter. Muatan asam amino dapat berubah positif atau negatif tergantung dari media sekitarnya (pelarut). Struktur gelatin terlihat seperti Gambar 2.2.

Kegunaan gelatin terutama adalah untuk mengubah cairan menjadi padatan yang elastis atau mengubah bentuk sol menjadi gel. Reaksi pembentukan gel oleh gelatin bersifat *reversible* karena bila gel dipanaskan akan terbentuk sol dan sewaktu didinginkan akan kembali terbentuk gel lagi. Keadaan tersebut membedakan dengan gel dari pektin, alginat, pati, albumin telur dan protein susu yang bentuk gelnya *irreversible.*



Gambar 2.2 Struktur kimia gelatin
(Sumber: Saleh, E., 2004)

2.7 Karakteristik Plastik Biodegradabel

Kualitas plastik biodegradabel yang dihasilkan dapat ditentukan dengan melakukan karakterisasi. Beberapa karakterisasi yang dapat menentukan kualitas plastik biodegradabel adalah karakterisasi sifat mekanik, karakterisasi gugus fungsi dengan FTIR, karakterisasi sifat termal meliputi titik leleh dan titik transisi kaca dengan DSC serta karakterisasi derajat kristalinitas (Juari, 2006).

Karakterisasi Sifat Mekanik

Sifat mekanik adalah sifat yang menyatakan kemampuan bahan dalam menerima beban tanpa menimbulkan kerusakan pada bahan tersebut. Untuk mendapatkan sifat mekanik material, biasanya dilakukan pengujian mekanik. Pengujian mekanik pada dasarnya bersifat merusak, dari pengujian tersebut akan dihasilkan data yang mencirikan keadaan dari material tersebut.

a. Kuat Lentur

Kelenturan adalah sifat material yang mampu menerima beban impak tinggi tanpa menimbulkan tegangan lebih pada batas elastis. Hal ini

menunjukkan bahwa energi yang diserap selama pembebanan disimpan dan dikeluarkan jika material tidak dibebani (Zainuri, 2008). Kuat lentur dapat dihitung dengan menggunakan Persamaan 2.1:

$$fr = \frac{3\,P.l}{2\,B.H^2} \qquad 2.1$$

Dimana:

P : Beban patah maksimum (N)

l : Jarak tumpuan (mm)

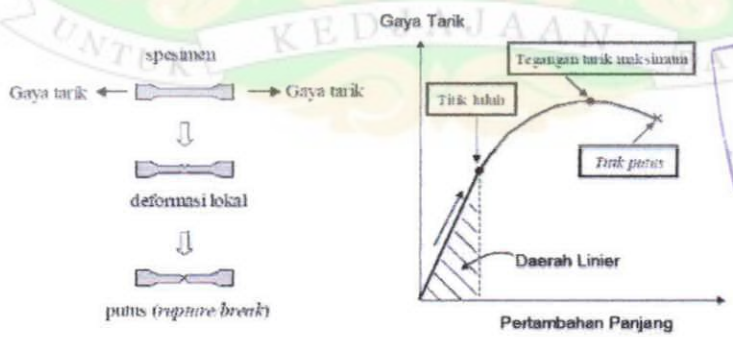
B : Lebar rata-rata benda uji (mm)

H : Tebal rata-rata benda uji (mm)

fr : Kuat lentur (N/mm^2)

b. Kuat Tarik

Uji tarik merupakan salah satu pengujian untuk mengetahui sifat-sifat suatu bahan. Dengan menarik suatu bahan kita akan segera mengetahui bagaimana bahan tersebut bereaksi terhadap tenaga tarikan dan mengetahui sejauh mana material itu bertambah panjang.



Gambar 2.3 Contoh Pengujian Tarik dan Kurva regangan-tegangan
(Sumber: www.alatuji.com)

Stress (Tegangan Mekanis):

$$\sigma = F/A \qquad 2.2$$

Strain (Regangan):

$$\varepsilon = \Delta L/L \qquad 2.3$$

Hubungan antara stress dan strain dirumuskan:

$$E = \sigma/\varepsilon \qquad 2.4$$

Dimana:

σ : Nilai tegangan (N/mm^2)

ε : Nilai regangan

ΔL : Pertambahan panjang (mm)

L : Panjang awal (mm)

F : Gaya tarikan (N)

A : Luas penampang (mm^2)

E : Modulus elastisitas (N/mm^2)

BAB III

METODE PENELITIAN

3.1 Waktu dan Tempat Penelitian

Peleburan dan pencetakan kemasan plastik PET bekas dan pati sagu dilakukan pada bulan Februari 2012 – Mei 2012 di Kampus Unand Limau Manis. Pengujian kuat lentur, kuat tarik dan struktur mikro dilakukan pada bulan Mei 2012 – Juli 2012 di Laboratorium Metalurgi, Jurusan Teknik Mesin, Fakultas Teknik, Universitas Andalas.

3.2 Bahan Penelitian

Bahan yang digunakan pada penelitian ini adalah:

a. Plastik Polietilen Tereftalat (PET) Bekas

Gambar 3.1 Plastik Polietilen Tereftalat

b. Tepung Sagu

Gambar 3.2 Tepung Sagu

c. Serbuk Gelatin

Gambar 3.3 Serbuk Gelatin

3.3 Alat yang Digunakan

Peralatan yang digunakan pada penelitian ini adalah sebagai berikut:

1) Kuali Besi

Kuali besi digunakan sebagai wadah untuk memanaskan plastik PET bekas, tepung sagu dan serbuk gelatin.

2) Timbangan digital

Timbangan digunakan untuk mengukur masa plastik PET bekas, tepung sagu dan serbuk gelatin.

Gambar 3.4 Timbangan Digital

Merek : Lutron

Jenis : GM-300P

Kapasitas : 300.00 g x 0.01 g

3) Kompor

Kompor digunakan sebagai sumber panas untuk memanaskan kuali besi.

4) Sendok kayu

Sendok kayu digunakan untuk mengaduk plastik dan meratakan campuran.

5) Cetakan Seng

Seng berfungsi sebagai cetakan sampel.

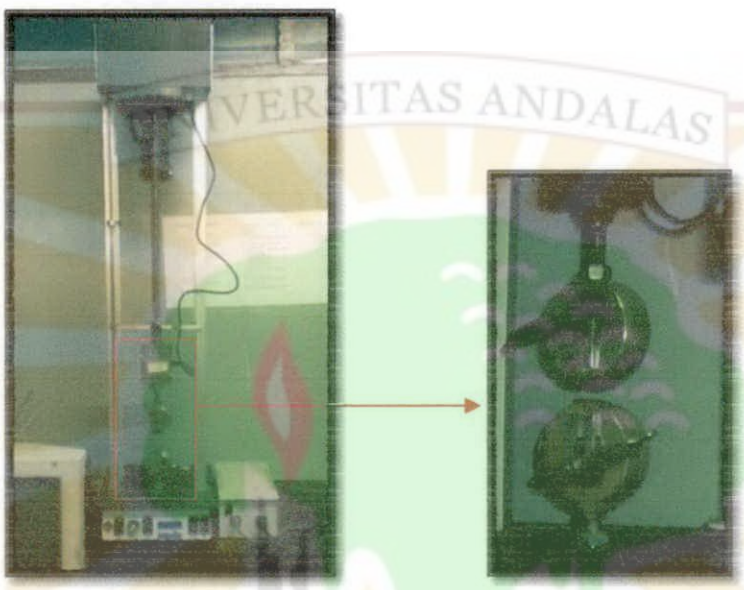
6) Mesin Uji Lentur (*Flexure*)

Mesin uji lentur merupakan mesin uji tarik mini *COM–TEN Testing Machine* yang dimodifikasi pada bagian pemegang spesimennya. Peralatan pencekam spesimen diganti dengan peralatan *flexure* tiga titik. Bentuk dari alat ini dapat dilihat pada Gambar 3.5.

Gambar 3.5 Mesin Uji Lentur Tiga Titik

7) Mesin Uji Tarik Mini

Pengujian tarik dilakukan dengan *COM–TEN Testing Machine* seperti pada Gambar 3.6.



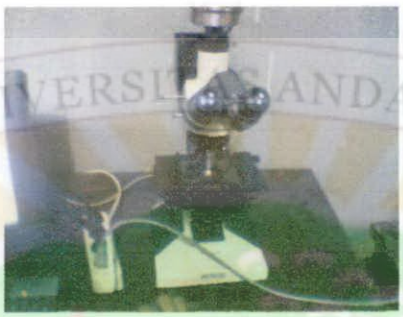
Gambar 3.6 COM–TEN *Testing Machine*

Spesifikasi alat uji tersebut sebagai berikut :

Merek	: *COM-TEN testing machine 95T series*
Kapasitas maksimum	: 5000 pounds
Range kecepatan	: 0,06 – 3 inchi/menit
Load cell	: *S-block load cell*
Kontrol pengujian	: Otomatis dengan *com-touch* total kontrol

8) Mikroskop Optik Digital

Digunakan untuk melihat struktur mikro sampel sebelum dan sesudah penguburan.



Gambar 3.7 Mikroskop Optik

Merek : JENCO

Jenis : MET-233

Perbesaran : 10 x, 20 x, 50 x dan 80 x

3.4 Teknik Penelitian

a. Persiapan Bahan

Persiapan bahan dimulai dari pengumpulan plastik PET bekas, tepung sagu dan serbuk gelatin. Plastik yang sudah terkumpul kemudian dipotong-potong menjadi ukuran kecil.

b. Pembuatan Cetakan

Pada penelitian ini cetakan yang digunakan terbuat dari seng plat. Ukuran cetakan untuk uji lentur adalah 127 mm x 12,7 mm x 3,2 mm. Sedangkan untuk pengujian tarik digunakan cetakan yang berukuran 165 mm x 19 mm dengan ketebalan kurang dari 7 mm.

c. Peleburan Plastik Kemasan Polietilen Tereftalat Bekas, Tepung Sagu dan Serbuk Gelatin

Pada penelitian ini akan dibuat 4 variasi massa serbuk gelatin, dengan massa plastik polietilen tereftalat dan tepung sagu tetap, yang ditunjukkan pada Tabel 3.1. Adapun variasi plastik polietilen tereftalat sebanyak 90 gram dan tepung sagu sebanyak 5 gram. Penambahan serbuk gelatin dimulai dari penambahan 5 g, 10 g dan 15 g.

Tabel 3.1 Komposisi Plastik Polietilen Tereftalat, Tepung Sagu dan Serbuk Gelatin

Plastik PET (g)	Tepung Sagu (g)	Serbuk Gelatin (g)
90	5	0
90	5	5
90	5	10
90	5	15

d. Mencetak

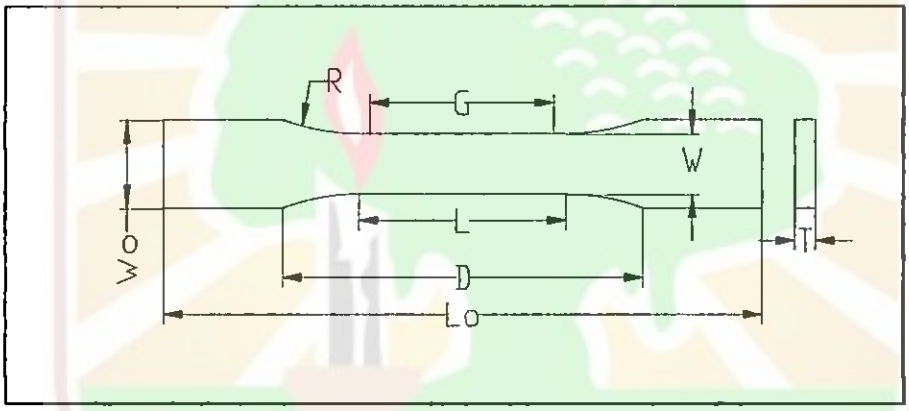
Campuran plastik kemasan polietilen tereftalat, tepung sagu dan serbuk gelatin yang telah mencair dalam wadah dituang ke dalam cetakan yang terbuat dari seng dan dibongkar setelah campuran tersebut membeku.

3.5 Teknik Pengujian

Semua pengujian didasarkan pada *American Society for Testing and Materials* (ASTM), untuk masing-masing pengujian standar yang digunakan yaitu, Uji Tarik menggunakan ASTM D638 dan Uji Lentur menggunakan ASTM D790.

3.5.1 Pengujian Tarik (*Tensile Test*)

Pengujian tarik dilakukan untuk mengetahui sifat mekanik komposit, yaitu dengan membentuk sampel sesuai standar kemudian ditarik hingga putus, dari pengujian tersebut diperoleh kurva antara tegangan dengan regangan yang terjadi, sehingga diperoleh kekuatan, ketangguhan, keuletan, dan modulus elastisitas komposit. Berdasarkan ASTM D638 ukuran spesimen dapat dilihat pada Gambar 3.8.



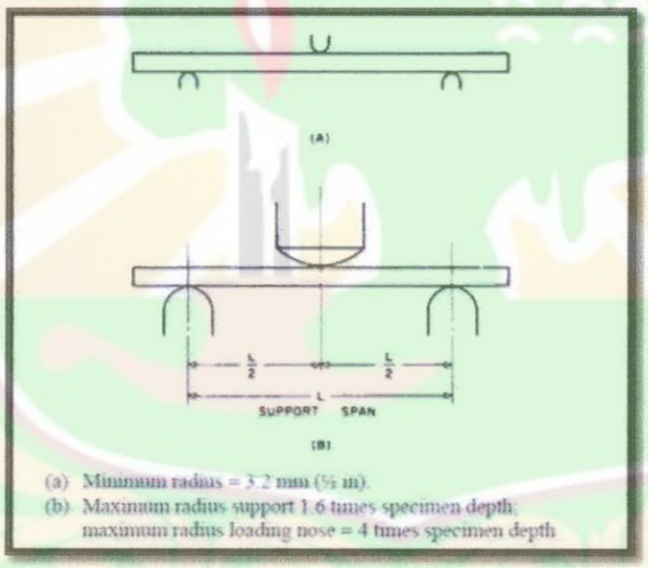
Gambar 3.8 Dimensi Spesimen Tarik Berdasarkan ASTM D638

Tabel 3.2 Ukuran Spesimen Berdasarkan ASTM D638

Spesifikasi	Ukuran (mm (in))
Ketebalan <7mm (0,28in), T	1,00 ± 0,4 (0,13 ± 0,02)
Lebar bagian kecil, W	13 (0,5)
Panjang bagian kecil, L	57 (2,25)
Lebar keseluruhan, Wo	19 (0,75)
Panjang keseluruhan, Lo	165 (6,5)
Panjang Gauge, G	50 (2,00)
Jarak antar grip, D	115 (4,5)
Radius fillet, R	76 (3,00)

3.5.2 Pengujian Lentur *(Flexural Test)*

Kekuatan lentur adalah kemampuan material untuk menahan gaya lentur yang diberikan dengan arah tegak lurus teradap penampang spesimen. Berdasarkan pada standar pengujian ASTM D790 pengujian ini dilakukan dengan memberikan gaya lentur pada spesimen yang berbentuk plat seperti pada Gambar 3.9, dimana dimensi spesiman adalah 127mm × 12,7mm × 3,2mm (5 in × ½ in × ⅛ in). Sesuai prosedur pada ASTM D790 spesimen harus diletakan pada tengah dengan toleransi 0,03 mm (0,001 in), jarak antar support (L) adalah 100 mm.



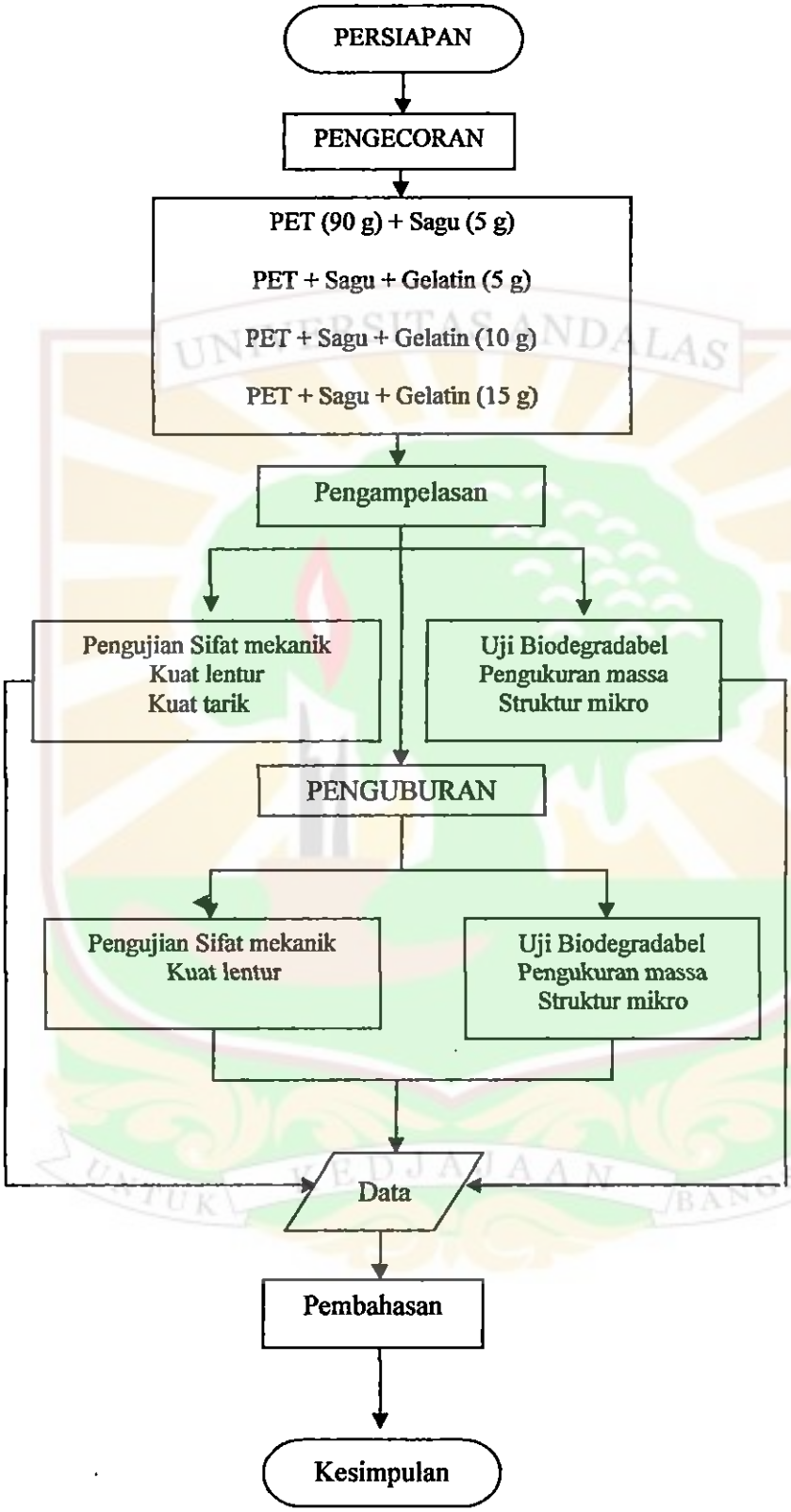
Gambar 3.9 Standar Pengujian Lentur ASTM D790

Pengujian dilakukan dengan menggunakan mesin alat uji tarik COM–TEN *testing machine* dengan peralatan tambahan (Gambar 3.5).

3.5.3 Uji Degradabilitas

Uji degradabilitas dilakukan dengan mengubur sampel di dalam tanah berlumpur. Waktu penguburan sampel divariasikan sebanyak empat variasi waktu

dengan maksimal waktu penguburan selama 40 hari. Selanjutnya dilihat perubahan fisis yang terjadi pada sampel. Perubahan fisis ini meliputi perubahan bentukan fisik sampel, struktur mikro yang dilihat dengan menggunakan Mikroskop Optik Digital, bentukan fisik dari sampel dilihat dari ada atau tidaknya lubang pada sampel akibat proses enzimatis mikroorganisme dan ada atau tidaknya pengurangan massa sesudah dilakukan penguburan.



Gambar 3.10 Skema Kerja Penelitian

BAB IV

HASIL DAN PEMBAHASAN

Berdasarkan penelitian yang telah dilakukan terhadap seluruh sampel uji, diperoleh data yang selanjutnya diolah sesuai dengan prosedur yang telah ditetapkan pada bagian metodologi sehingga diperoleh parameter-parameter yang diinginkan. Sebagai analisa data hasil pengujian, dilakukan pembahasan terhadap masing-masing objek tersebut. Berikut ini adalah uraian lengkap mengenai hasil dan pembahasan penelitian tersebut.

4.1 Hasil Pengujian Kuat Lentur Plastik PET Bekas Campuran Pati Sagu dan Serbuk Gelatin

Nilai kuat lentur plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin tanpa penguburan disajikan pada Tabel 4.1:

Tabel 4.1 Hasil Pengujian Kuat Lentur Tanpa Penguburan

Variasi Sampel	Kuat Lentur (N/mm^2)			Rata-rata
	1	2	3	
90 g : 5 g : 0	4,346	34,546	34,698	24,53
90 g : 5 g : 5 g	6,634	7,947	7,264	7,282
90 g : 5 g : 10 g	8,901	10,1	7,831	8,944
90 g : 5 g : 15 g	14,148	13,208	15,178	14,178

Dari hasil pengujian sampel yang telah dilakukan, maka didapatkan nilai maksimal kuat lentur pada sampel tanpa penambahan serbuk gelatin senilai 24,53 N/mm^2 dan nilai minimum kuat lentur pada sampel dengan penambahan serbuk gelatin sebanyak 5 g yaitu sebesar 7,282 N/mm^2.

Pada Tabel 4.2 dapat dilihat nilai kuat lentur plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin setelah ditanam dalam tanah selama 10 hari:

Tabel 4.2 Hasil Pengujian Kuat Lentur Dengan Penguburan 10 Hari

Variasi Sampel	Kuat Lentur (N/mm^2)			Rata-rata
	1	2	3	
90 g : 5 g : 0	15,486	23,905	39,87	26,42
90 g : 5 g : 5 g	24,294	23,008	21,978	23,093
90 g : 5 g : 10 g	22,943	20,898	19,041	20,961
90 g : 5 g : 15 g	data tidak dapat diambil			

Untuk kuat lentur plastik dengan penguburan 10 hari diperoleh nilai maksimum sebesar 26,42 N/mm^2 yang didapatkan dari sampel plastik tanpa penambahan serbuk gelatin dan nilai minimum sebesar 20,961 N/mm^2 yang didapatkan dari sampel plastik dengan penambahan 10 g serbuk gelatin. Sedangkan sampel dengan penambahan serbuk gelatin sebanyak 15 g tidak dapat diujikan karena sampel patah saat dilakukan penguburan.

Tabel 4.3 menunjukkan nilai kuat lentur plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin setelah ditanam dalam tanah selama 20 hari:

Tabel 4.3 Hasil Pengujian Kuat Lentur Dengan Penguburan 20 Hari

Variasi Sampel	Kuat Lentur (N/mm^2)			Rata-rata
	1	2	3	
90 g : 5 g : 0	26,828	2,828	26,828	18,828
90 g : 5 g : 5 g	20,694	21,46	20,565	20,906
90 g : 5 g : 10 g	16,366	19,568	17,903	17,945
90 g : 5 g : 15 g	data tidak dapat diambil			

Pada pengujian kuat lentur tanpa penguburan dan dengan penguburan 10 hari, nilai kuat lentur tertinggi didapatkan dari sampel tanpa penambahan serbuk gelatin. Pada penguburan 20 hari nilai kuat lentur maksimum sebesar 20,906 N/mm^2 didapatkan pada sampel dengan penambahan serbuk gelatin sebanyak 5 g dan nilai minimum kuat lentur adalah 17,945 N/mm^2 didapatkan pada sampel dengan penambahan serbuk gelatin sebanyak 10g. Sedangkan sampel plastik dengan penambahan serbuk gelatin sebanyak 15 g telah patah saat dilakukan penguburan, sehingga sampel tidak dapat diuji nilai kuat lenturnya.

Pada Tabel 4.4 dapat dilihat nilai kuat lentur plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin setelah ditanam di dalam tanah selama 30 hari:

Tabel 4.4 Hasil Pengujian Kuat Lentur Dengan Penguburan 30 Hari

Variasi Sampel	Kuat Lentur (N/mm^2)			Rata-rata
	1	2	3	
90 g : 5 g : 0	36,899	47,368	11,262	31,843
90 g : 5 g : 5 g	11,794	16,841	6,637	11,757
90 g : 5 g : 10 g	12,795	16,82	8,789	12,798
90 g : 5 g : 15 g	data tidak dapat diambil			

Nilai maksimum kuat lentur yang sangat signifikan didapatkan pada sampel plastik tanpa penambahan serbuk gelatin, dimana nilai kuat lentur yang didapatkan adalah sebesar 31,843 N/mm^2. Nilai tersebut merupakan nilai kuat lentur tertinggi yang didapatkan dari keseluruhan sampel plastik. Nilai kuat lentur minimum didapatkan pada sampel dengan penambahan 5 g serbuk gelatin, yaitu sebesar 11,757 N/mm^2.

Tabel 4.5 menunjukkan nilai kuat lentur plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin setelah ditanam di dalam tanah selama 40 hari:

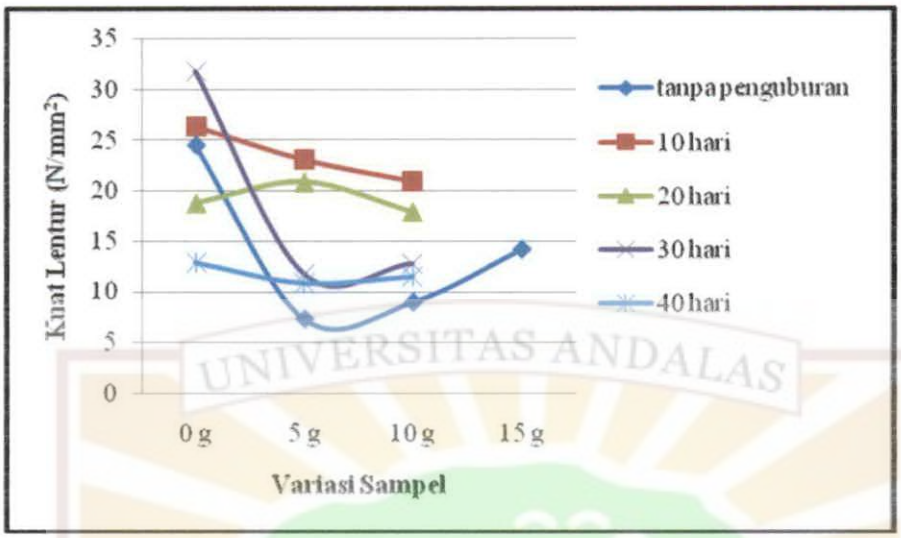
Tabel 4.5 Hasil Pengujian Kuat Lentur Dengan Penguburan 40 Hari

Variasi Sampel	Kuat Lentur (N/mm^2)			Rata-rata
	1	2	3	
90 g : 5 g : 0	12,609	13,956	12,137	12,9
90 g : 5 g : 5 g	7,583	8,925	15,988	10,832
90 g : 5 g : 10 g	13,978	8,994	11,522	11,498
90 g : 5 g : 15 g	data tidak dapat diambil			

Kekuatan lentur sampel plastik makin menurun karena semakin lama dilakukan penguburan. Pada variasi waktu penguburan selama 40 hari diperoleh nilai maksimum kuat lentur sebesar 12,9 N/mm^2 yang didapatkan dari sampel tanpa penambahan serbuk geatin. Nilai kuat lentur minimum sebesar 10,498 N/mm^2

didapatkan dari sampel dengan penambahan serbuk gelatin sebanyak 5 g.

Berdasarkan data kuat lentur yang diperoleh dari semua sampel, maka didapatkan grafik seperti Gambar 4.1. Pada Gambar 4.1 dapat dilihat perbandingan kekuatan lentur plastik dengan variasi penambahan serbuk gelatin sebesar 0 g, 5 g, 10 g dan 15 g. Nilai kuat lentur plastik tersebut juga dibandingakan dengan variasi waktu penguburan sampel plastik sebanyak 4 variasi waktu, yaitu selama 10 hari, 20 hari, 30 hari dan 40 hari.



Gambar 4.1 Grafik Perbandingan Kuat Lentur Sampel Plastik dengan Variasi Waktu Penguburan

Dari grafik terlihat bahwa semakin lama waktu penguburan yang dilakukan pada sampel plastik, maka nilai kuat lentur yang dimiliki sampel plastik semakin berkurang, terlihat dari bentukan grafik yang semakin menurun. Ini dapat menjadi bukti bahwa plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin merupakan plastik biodegradabel.

Nilai kuat lentur yang semakin berkurang disebabkan oleh kerusakan sampel yang terjadi semakin banyak karena terjadinya pemutusan ikatan polimer oleh mikroorganisme di dalam tanah yang akhirnya menyebabkan penurunan kuat lentur sampel plastik. Hal ini diperkirakan karena plastik biodegradabel adalah suatu bahan dalam kondisi tertentu dan pada waktu tertentu mengalami perubahan dalam struktur fisis dan kimianya karena pengaruh mikroorganisme yang kemudian mempengaruhi sifat-sifat yang dimilikinya (Firdaus, F. dan Chairil Anwar, 2004). Hal ini juga dapat terjadi karena tambahan material organik berupa

tepung sagu dan serbuk gelatin dalam campuran plastik PET tersebut yang memudahkan mikroorganisme dalam proses penguraian.

Nilai kuat lentur yang didapatkan sampel plastik sangat bervariasi. Pada sampel plastik tanpa penguburan didapatkan nilai kuat lentur yang rendah dibandingkan setelah sampel plastik dibenamkan ke tanah dan nilai kuat lentur tertinggi sebagian besar dimiliki oleh sampel plastik tanpa penambahan serbuk gelatin. Hal ini dapat terjadi karena tekstur serbuk gelatin yang sulit untuk bercampur dengan bahan plastik PET dan pati sagu menyebabkan serbuk gelatin harus dipanaskan terlebih dahulu sampai berubah menjadi berwarna kecoklatan. Perlakukan ini menjadikan ikatan yang terdapat pada serbuk gelatin terputus. Karena serbuk gelatin yang termasuk dalam gugus protein akan mudah rusak ikatannya bila dipanaskan, istilah ini dikenal juga dengan denaturasi protein.

Namun setelah dilakukan penguburan nilai kuat lentur yang didapatkan dari sampel plastik menjadi lebih tinggi. Kandungan air yang terdapat di dalam tanah ikut mempengaruhi kekuatan lentur plastik tersebut. Serbuk gelatin dan tepung sagu yang bersifat menyerap air, setelah dibenamkan ke tanah selama 10 hari meningkat kekuatan lenturnya karena serbuk gelatin dan tepung sagu jika dicampur dengan air akan meningkat keelastisannya dan bersifat lengket. Hal ini menyebabkan meningkatnya kuat lentur sampel plastik setelah dilakukan penguburan selama 10 hari.

Penambahan serbuk gelatin terhadap sifat mekanik dari plastik PET campuran pati sagu tidak memberi pengaruh besar terhadap nilai kuat lenturnya. Dapat dilihat pada Gambar 4.1 dari variasi waktu penguburan nilai kuat lentur

plastik PET campuran pati sagu tanpa penambahan serbuk gelatin merupakan kuat lentur yang paling tinggi. Perubahan terjadi pada penguburan 20 hari, dimana nilai kuat lentur tertinggi dimiliki oleh sampel dengan penambahan serbuk gelatin sebanyak 5 g. Ini dikarenakan bahan serbuk gelatin yang sulit bercampur dengan plastik PET dan pati sagu menyebabkan serbuk gelatin tersebut tidak tercampur merata di seluruh permukaan sampel menyebabkan pembentukan pori pada sampel semakin banyak. Pori yang dimiliki oleh material merupakan suatu cacat yang dapat mempengaruhi kekuatan mekanis suatu bahan (Efilusi, D., 2012).

Pengaruh terhadap sifat mekanik ini disebabkan juga oleh penurunan affinitas dengan adanya penambahan gelatin. Menurut Weiping Ban, faktor penting yang mempengaruhi sifat mekanik pada suatu film plastik adalah affinitas antara tiap komponen penyusunnya. Affinitas adalah suatu fenomena dimana atom atau molekul tertentu memiliki kecenderungan untuk bersatu atau berikatan. Jika terjadi peningkatan affinitas maka semakin banyak terjadi ikatan antar molekul. Kekuatan suatu bahan dipengaruhi oleh ikatan kimia penyusunnya. Ikatan kimia yang kuat bergantung pada jumlah ikatan molekul dan jenis ikatannya (seperti ikatan kovalen, ion, hidrogen dan Van der Waals). Ikatan kimia yang kuat sulit untuk diputus karena diperlukan energi yang cukup besar untuk memutus ikatan tersebut.

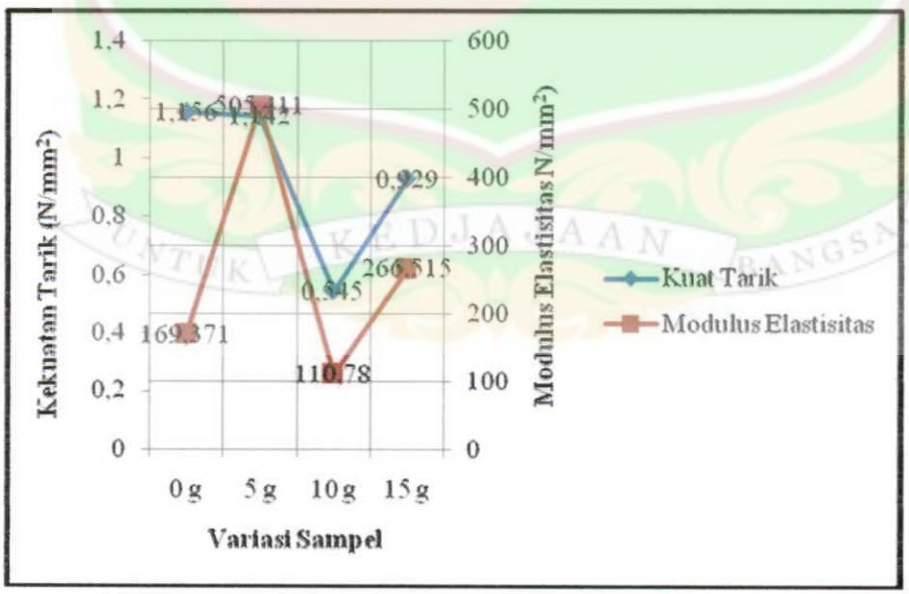
4.2 Hasil Pengujian Kuat Tarik Plastik PET Bekas Campuran Pati Sagu dan Serbuk Gelatin

Tabel 4.6 menunjukkan nilai kuat tarik dan modulus elastisitas plastik PET bekas campuran pati sagu dan serbuk gelatin:

Tabel 4.6 Hasil Uji Tarik Plastik PET Bekas Campuran Pati Sagu dan Serbuk Gelatin

Variasi Sampel	Kuat Tarik (N/mm^2)			Rata-rata	Modulus Elastisitas (N/mm^2)			Rata-rata
	1	2	3		1	2	3	
90 g : 5 g : 0	1,3661	0,424	1,679	1,156	167,488	212,244	128,381	169,371
90 g : 5 g : 5 g	0,319	1,957	1,151	1,142	109,044	1157,88	249,311	505,411
90 g : 5 g : 10 g	0,545	0,545	0,545	0,545	110,78	110,78	110,78	110,78
90 g : 5 g : 15 g	1,131	0,762	0,894	0,929	350,157	34,874	414,515	266,515

Dari tabel dapat dilihat kekuatan tarik maksimum terdapat pada sampel tanpa penambahan serbuk gelatin yaitu sebesar 1,156 N/mm^2 dan kekuatan tarik minimum 0,545 terdapat pada sampel uji dengan penambahan serbuk gelatin sebanyak 10 g. Adapun hal yang mempengaruhi nilai modulus elastisitas plastik adalah gaya yang diterima sampel uji ketika pengujian dan pertambahan panjang sampel ketika diberi gaya tarikan pada saat pengujian. Grafik nilai kuat lentur plastik PET bekas campuran pati sagu dan serbuk gelatin dapat dilihat pada gambar 4.7.



Gambar 4.2 Grafik Kekuatan Tarik dan Modulus Elastisitas Plastik

Pada Gambar 4.2 dapat dilihat grafik kekuatan tarik plastik Polietilen Tereftalat bekas campuran pati sagu dan serbuk gelatin. Nilai kuat tarik paling tinggi didapatkan dari sampel tanpa penambahan serbuk gelatin, namun modulus elastisitas sampel tersebut menurun karena ketika sampel diuji tarik pertambahan panjang sampel semakin besar. Sampel plastik yang bersifat getas dan mudah patah ikut mempengaruhi kekuatan tarik plastik tersebut, semakin tinggi tingkat kegetasan suatu sampel maka nilai kuat tarik yang diperoleh akan semakin kecil.

Pencampuran yang tidak merata pada sampel plastik menyebabkan nilai kuat tarik yang diperoleh menjadi tidak stabil. Dapat dilihat dari Gambar 4.2 kuat tarik pada sampel dengan penambahan serbuk gelatin sebanyak 5 g menjadikan nilai kuat tarik sampel menurun, ketika penambahan serbuk gelatin ditingkatkan menjadi 10 g nilai kuat tarik semakin turun, namun pada penambahan serbuk gelatin sebanyak 15 g nilai kuat tarik meningkat. Kesulitan dalam melakukan pencampuran serbuk gelatin pada sampel plastik tersebut menyebabkan serbuk gelatin tidak tercampur sempurna.

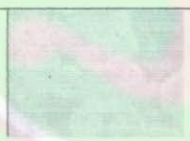
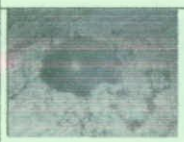
4.3 Biodegradabilitas Plastik PET Bekas Campuran Pati Sagu dan Serbuk Gelatin

Untuk membuktikan terjadi degradasi pada sampel plastik, maka dilakukan pengujian terhadap struktur mikro permukaan plastik dan pengukuran massa plastik sebelum dan sesudah dilakukan penguburan. Foto struktur mikro ini berguna untuk melihat perubahan fisik sampel setelah dilakukan penguburan di dalam tanah.

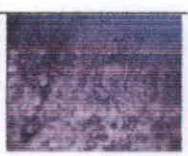
4.3.1 Perubahan Fisik Plastik PET Bekas Campuran Pati Sagu dan Serbuk Gelatin

Setelah dilakukan pengujian terlihat perubahan fisik sampel. Struktur permukaan plastik berubah, hal ini terlihat dari permukaan plastik yang semakin kasar dan semakin banyak pori yang terdapat pada permukaan plastik tersebut. Semakin lama waktu penguburan kerusakan yang dialami semakin banyak. Bahkan sampel dengan penambahan gelatin sebanyak 15 g tidak hanya mengalami penambahan pori, namun juga mengalami keretakan di bagian permukaannya. Berikut merupakan hasil foto sampel plastik setelah sampel plastik ditanam di dalam tanah sesuai waktu yang ditentukan pada metode penelitian ini. Hasil foto tersebut diambil dengan menggunakan mikroskop optik

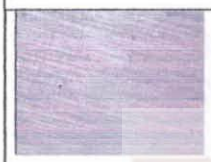
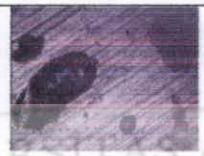
a. Sampel Plastik Tanpa Penambahan Serbuk Gelatin

Sebelum penguburan	Penguburan 10 hari	Penguburan 20 hari	Penguburan 30 hari	Penguburan 40 hari
				

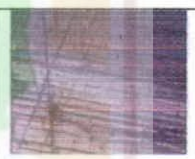
b. Sampel Plastik Dengan Penambahan Serbuk Gelatin Sebanyak 5 g

Sebelum penguburan	Penguburan 10 hari	Penguburan 20 hari	Penguburan 30 hari	Penguburan 40 hari
				

c. Sampel Plastik Dengan Penambahan Serbuk Gelatin Sebanyak 10 g

Sebelum penguburan	Penguburan 10 hari	Penguburan 20 hari	Penguburan 30 hari	Penguburan 40 hari
				

d. Sampel Plastik Dengan Penambahan Serbuk Gelatin Sebanyak 15 g

Sebelum penguburan	Penguburan 10 hari	Penguburan 20 hari	Penguburan 30 hari	Penguburan 40 hari
				

4.3.2 Perubahan Massa Plastik

Faktor lain yang digunakan untuk melihat degradasi sampel akibat mikroorganisme adalah dengan melihat pengurangan massa sampel plastik setelah dilakukan penguburan. Pada Tabel 4.7 dapat dilihat perubahan massa sampel plastik setelah dilakukan penguburan selama 10 hari.

Tabel 4.7 Perubahan Massa Plastik Setelah Penguburan 10 Hari

Kode sampel	massa awal (g)	massa akhir (g)	dm (g)	degradasi (%)
Penambahan 0 g	9,260	9,250	0,010	0,108
	11,070	11,070	0,000	0,000
	9,950	9,932	0,018	0,181
Rata-rata	10,093	10,084	0,009	0,096
Penambahan 5 g	12,660	12,650	0,010	0,079
	11,120	11,100	0,020	0,180
	11,890	11,875	0,015	0,126
Rata-rata	11,890	11,875	0,015	0,128
Penambahan 10 g	12,530	11,540	0,990	7,901
	12,120	11,890	0,230	1,898
	12,325	11,100	1,225	9,939
Rata-rata	12,325	11,510	0,815	6,579
Penambahan 15 g	13,680	11,190	2,490	18,202
	13,660	11,200	2,460	18,009
	13,500	11,170	2,330	17,259
Rata-Rata	13,613	11,187	2,427	17,823

Pada Tabel 4.8 dapat dilihat perubahan massa plastik setelah dilakukan penguburan selama 20 hari.

Tabel 4.8 Perubahan Massa Plastik Setelah Penguburan 20 hari

Kode sampel	massa awal (g)	massa akhir (g)	dm (g)	degradasi (%)
Penambahan 0 g	10,310	10,250	0,060	0,582
	10,600	10,550	0,050	0,472
	10,600	10,560	0,040	0,377
Rata-rata	10,503	10,453	0,050	0,477
Penambahan 5 g	13,120	13,100	0,020	0,152
	12,730	12,500	0,230	1,807
	13,690	13,140	0,550	4,018
Rata-rata	13,180	12,913	0,267	1,992
Penambahan 10 g	12,570	11,180	1,390	11,058
	12,960	10,670	2,290	17,670
	12,765	10,925	1,840	14,414
Rata-rata	12,765	10,925	1,840	14,381
Penambahan 15 g	13,100	10,490	2,610	19,924
	13,250	10,500	2,750	20,755
	13,400	10,300	3,100	23,134
Rata-Rata	13,250	10,430	2,820	21,271

Pada Tabel 4.9 dapat dilihat perubahan massa plastik setelah dilakukan penguburan selama 30 hari.

Tabel 4.9 Perubahan Massa Plastik Setelah Penguburan 30 hari

Kode sampel	massa awal (g)	massa akhir (g)	dm (g)	degradasi (%)
Penambahan 0 g	9,440	9,310	0,130	1,377
	7,600	7,480	0,120	1,579
	9,060	8,970	0,090	0,993
Rata-rata	8,700	8,587	0,113	1,316
Penambahan 5 g	13,610	12,160	1,450	10,654
	13,750	13,300	0,450	3,273
	15,970	15,800	0,170	1,064
Rata-rata	14,443	13,753	0,690	4,997
Penambahan 10 g	12,170	11,300	0,870	7,149
	14,720	13,520	1,200	8,152
	13,360	11,420	1,940	14,521
Rata-rata	13,417	12,080	1,337	11,337
Penambahan 15 g	14,080	12,320	1,760	12,500
	14,300	11,760	2,540	17,762
	14,200	10,120	4,080	28,732
Rata-Rata	14,250	10,940	3,310	23,247

Pada Tabel 4.10 dapat dilihat perubahan massa plastik setelah dilakukan penguburan selama 40 hari.

Tabel 4.10 Perubahan Massa Plastik Setelah Penguburan 40 hari

Kode sampel	massa awal (g)	massa akhir (g)	dm (g)	degradasi (%)
Penambahan 0 g	12,840	12,650	0,190	1,480
	10,150	9,990	0,160	1,576
	9,520	9,390	0,130	1,366
Rata-rata	10,837	10,677	0,160	1,474
Penambahan 5 g	13,720	11,930	1,790	13,047
	11,430	11,050	0,380	3,325
	12,770	12,700	0,070	0,548
Rata-rata	12,640	11,893	0,747	5,640
Penambahan 10 g	12,640	10,190	2,450	19,383
	12,210	10,070	2,140	17,527
	11,250	9,700	1,550	13,778
Rata-rata	12,033	9,987	2,047	16,896
Penambahan 15 g	12,590	9,230	3,360	26,688
	12,590	9,650	2,940	23,352
	12,590	9,430	3,160	25,099
Rata-Rata	12,590	9,437	3,153	25,046

Dari tabel perubahan massa, terlihat bahwa massa sampel setelah penguburan yang berkurang karena terdegradasi oleh mikroba. Pada sampel tanpa penambahan serbuk gelatin pengurangan massa yang terjadi setelah penguburan hanya sedikit. Penambahan serbuk gelatin ditingkatkan menjadi 5 g, 10 g dan 15 g, pada penambahan 15 g terjadi pengurangan massa yang semakin banyak. Hal ini menunjukkan degradasi plastik semakin besar karena penambahan biopolimer berupa serbuk gelatin yang semakin banyak karena serbuk gelatin yang merupakan bahan alami dapat berkurang karena aktivitas mikroorganisme di dalam tanah.

BAB V

KESIMPULAN DAN SARAN

5.1 Kesimpulan

Dari penelitian yang telah dilakukan mengenai kuat lentur plastik PET bekas campuran pati sagu dan serbuk gelatin, maka dapat disimpulkan:

a. Serbuk gelatin kurang efektif ditambahkan sebagai pemlastis. Dapat terlihat dari data kuat lentur yang diperoleh dari penelitian ini, nilai kuat lentur tertinggi didapatkan dari sampel uji dengan campuran 90 g plastik PET bekas, 5 g pati sagu tanpa penambahan serbuk gelatin. Penurunan kekuatan lentur sampel uji terjadi di tiap penambahan waktu penguburan. Semakin lama waktu penguburan sampel, maka kekuatan lentur sampel semakin berkurang.

b. Nilai kuat tarik tertinggi didapatkan dari sampel tanpa penambahan serbuk gelatin, yakni sebesar 1,156 N/mm^2. Modulus elastisitas tertinggi didapatkan dari sampel dengan penambahan serbuk gelatin sebanyak 5 g, sebesar 505,411 N/mm^2.

c. Dari keseluruhan variasi, didapatkan sampel yang paling cepat terdegradasi adalah sampel dengan penambahan 15 g serbuk gelatin, hal ini dapat terlihat dari perubahan fisik sampel dan struktur mikro permukaan sampel tersebut.

5.2 Saran

Agar penelitian dapat diperoleh hasil yang maksimal, maka disarankan kepada peneliti selanjutnya:

a. Untuk dapat memperkecil penambahan sebuk gelatin dan menambah variasi sampel uji, karena semakin banyak variasi penambahan akan lebih terlihat pengaruh penambahan pemlastis tersebut.
b. Dalam pembuatan sampel hendaknya menggunakan *blending* dalam proses pencampuran agar bahan tercampur merata, untuk proses pencetakan menggunakan *hot press* untuk meminimalisir terbentuknya pori (void) pada sampel yang dapat mengganggu kekuatan mekanis bahan.
c. Sebaiknya lokasi tempat penguburan diisolasi, sehingga proses degradasinya tidak dipengaruhi oleh lingkungan sekitar seperti air dan sebagainya.

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Designation: D 638 – 02

An American National Standard

Standard Test Method for Tensile Properties of Plastics[1]

This standard is issued under the fixed designation D 638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

s test method covers the determination of the tensile of unreinforced and reinforced plastics in the form l dumbbell-shaped test specimens when tested under nditions of pretreatment, temperature, humidity, and chine speed.

s test method can be used for testing materials of any up to 14 mm (0.55 in.). However, for testing in the form of thin sheeting, including film less than 0.04 in.) in thickness, Test Methods D 882 is the est method. Materials with a thickness greater than 55 in.) must be reduced by machining.

s test method includes the option of determining ratio at room temperature.

This test method and ISO 527-1 are technically equivalent.

This test method is not intended to cover precise physical It is recognized that the constant rate of crosshead movement leaves much to be desired from a theoretical standpoint, that nces may exist between rate of crosshead movement and rate ween gage marks on the specimen, and that the testing speeds sguise important effects characteristic of materials in the Further, it is realized that variations in the thicknesses of test which are permitted by these procedures, produce variations in volume ratios of such specimens, and that these variations may e test results. Hence, where directly comparable results are samples should be of equal thickness. Special additional tests sed where more precise physical data are needed.

This test method may be used for testing phenolic molded inated materials. However, where these materials are used as sulation, such materials should be tested in accordance with ls D 229 and Test Method D 651.

For tensile properties of resin-matrix composites reinforced ed continuous or discontinuous high modulus >20-GPa -psi) fibers, tests shall be made in accordance with Test 039/D 3039M.

: data obtained by this test method are relevant and e for use in engineering design.

values stated in SI units are to be regarded as the The values given in parentheses are for information

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation[2]

D 412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension[3]

D 618 Practice for Conditioning Plastics for Testing[4]

D 651 Test Method for Tensile Strength of Molded Electrical Insulating Materials[5]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[4]

D 883 Terminology Relating to Plastics[4]

D 1822 Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials[4]

D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials[6]

D 4000 Classification System for Specifying Plastic Materials[7]

D 4066 Classification System for Nylon Injection and Extrusion Materials[7]

D 5947 Test Methods for Physical Dimensions of Solid Plastic Specimens[8]

E 4 Practices for Force Verification of Testing Machines[9]

E 83 Practice for Verification and Classification of Extensometer[9]

E 132 Test Method for Poisson's Ratio at Room Temperature[9]

E 691 Practice for Conducting an Interlaboratory Study to

method is under the jurisdiction of ASTM Committee D20 on Plastics ct responsibility of Subcommittee D20.10 on Mechanical Properties.
lition approved April 10, 2002. Published June 2002. Originally D 638 – 41 T. Last previous edition D 638 – 01.

[2] *Annual Book of ASTM Standards*, Vol 10.01.
[3] *Annual Book of ASTM Standards*, Vol 09.01.
[4] *Annual Book of ASTM Standards*, Vol 08.01.
[5] Discontinued; see *1994 Annual Book of ASTM Standards*, Vol 10.01.
[6] *Annual Book of ASTM Standards*, Vol 15.03.
[7] *Annual Book of ASTM Standards*, Vol 08.02.
[8] *Annual Book of ASTM Standards*, Vol 08.03.
[9] *Annual Book of ASTM Standards*, Vol 03.01.

***A Summary of Changes section appears at the end of this standard.**

TM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

ne the Precision of a Test Method[10]
Standard:
Determination of Tensile Properties[11]

logy

itions—Definitions of terms applying to this test
ear in Terminology D 883 and Annex A2.

nce and Use

est method is designed to produce tensile property
control and specification of plastic materials. These
o useful for qualitative characterization and for
development. For many materials, there may be a
that requires the use of this test method, but with
dural modifications that take precedence when
he specification. Therefore, it is advisable to refer
erial specification before using this test method.
Classification D 4000 lists the ASTM materials
at currently exist.

le properties may vary with specimen preparation
eed and environment of testing. Consequently,
se comparative results are desired, these factors
fully controlled.

realized that a material cannot be tested without
he method of preparation of that material. Hence,
rative tests of materials per se are desired, the
must be exercised to ensure that all samples are
exactly the same way, unless the test is to include
f sample preparation. Similarly, for referee pur-
nparisons within any given series of specimens,
taken to secure the maximum degree of unifor-
ils of preparation, treatment, and handling.

le properties may provide useful data for plastics
design purposes. However, because of the high
ensitivity exhibited by many plastics to rate of
d environmental conditions, data obtained by this
cannot be considered valid for applications involv-
ne scales or environments widely different from
s test method. In cases of such dissimilarity, no
mation of the limit of usefulness can be made for
s. This sensitivity to rate of straining and environ-
itates testing over a broad load-time scale (includ-
nd creep) and range of environmental conditions if
erties are to suffice for engineering design pur-

nce the existence of a true elastic limit in plastics (as in
rganic materials and in many metals) is debatable, the
pplying the term "elastic modulus" in its quoted, generally
ition to describe the "stiffness" or "rigidity" of a plastic has
questioned. The exact stress-strain characteristics of plastic
highly dependent on such factors as rate of application of
ature, previous history of specimen, etc. However, stress-
for plastics, determined as described in this test method,
show a linear region at low stresses, and a straight line
to this portion of the curve permits calculation of an elastic
modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

4.4 *Poisson's Ratio*—When uniaxial tensile force is applied to a solid, the solid stretches in the direction of the applied force (axially), but it also contracts in both dimensions lateral to the applied force. If the solid is homogeneous and isotropic, and the material remains elastic under the action of the applied force, the lateral strain bears a constant relationship to the axial strain. This constant, called Poisson's ratio, is defined as the negative ratio of the transverse (negative) to axial strain under uniaxial stress.

4.4.1 Poisson's ratio is used for the design of structures in which all dimensional changes resulting from the application of force need to be taken into account and in the application of the generalized theory of elasticity to structural analysis.

NOTE 6—The accuracy of the determination of Poisson's ratio is usually limited by the accuracy of the transverse strain measurements because the percentage errors in these measurements are usually greater than in the axial strain measurements. Since a ratio rather than an absolute quantity is measured, it is only necessary to know accurately the relative value of the calibration factors of the extensometers. Also, in general, the value of the applied loads need not be known accurately.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member of the testing machine can be either the fixed or self-aligning type.

5.1.3.1 Fixed grips are rigidly attached to the fixed and movable members of the testing machine. When this type of grip is used extreme care should be taken to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincides with the direction of pull through the center line of the grip assembly.

5.1.3.2 Self-aligning grips are attached to the fixed and movable members of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.3 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (0.09 in.) apart and about 1.6 mm (0.06 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations

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, NY 10036.

kept clean and sharp. Breaking in the grips may
mes, even when deep serrations or abraded specimen
re used; other techniques must be used in these cases.
niques that have been found useful, particularly with
ced grips, are abrading that portion of the surface of
nen that will be in the grips, and interposing thin
abrasive cloth, abrasive paper, or plastic, or rubber-
ric, commonly called hospital sheeting, between the
and the grip surface. No. 80 double-sided abrasive
been found effective in many cases. An open-mesh
which the threads are coated with abrasive, has also
tive. Reducing the cross-sectional area of the speci-
also be effective. The use of special types of grips is
s necessary to eliminate slippage and breakage in the

rive Mechanism—A drive mechanism for imparting
vable member a uniform, controlled velocity with
the stationary member, with this velocity to be
as specified in Section 8.

oad Indicator—A suitable load-indicating mecha-
ble of showing the total tensile load carried by the
nen when held by the grips. This mechanism shall be
free of inertia lag at the specified rate of testing and
cate the load with an accuracy of ±1 % of the
value, or better. The accuracy of the testing machine
erified in accordance with Practices E 4.

Experience has shown that many testing machines now in use
e of maintaining accuracy for as long as the periods between
ecommended in Practices E 4. Hence, it is recommended that
ne be studied individually and verified as often as may be
ssary. It frequently will be necessary to perform this function

he fixed member, movable member, drive mecha-
grips shall be constructed of such materials and in
ortions that the total elastic longitudinal strain of the
nstituted by these parts does not exceed 1 % of the
tudinal strain between the two gage marks on the test
at any time during the test and at any load up to the
city of the machine.

ension Indicator (extensometer)—A suitable instru-
l be used for determining the distance between two
d points within the gage length of the test specimen as
hen is stretched. For referee purposes, the extensom-
be set at the full gage length of the specimen, as
Fig. 1. It is desirable, but not essential, that this
t automatically record this distance, or any change in
unction of the load on the test specimen or of the
me from the start of the test, or both. If only the latter
d, load-time data must also be taken. This instrument
essentially free of inertia at the specified speed of
xtensometers shall be classified and their calibration
ly verified in accordance with Practice E 83.

Modulus-of-Elasticity Measurements—For modulus-
ty measurements, an extensometer with a maximum
or of 0.0002 mm/mm (in./in.) that automatically and
sly records shall be used. An extensometer classified
ce E 83 as fulfilling the requirements of a B-2
ion within the range of use for modulus measure-
ments meets this requirement.

5.2.2 *Low-Extension Measurements*—For elongation-at-yield and low-extension measurements (nominally 20 % or less), the same above extensometer, attenuated to 20 % extension, may be used. In any case, the extensometer system must meet at least Class C (Practice E 83) requirements, which include a fixed strain error of 0.001 strain or ±1.0 % of the indicated strain, whichever is greater.

5.2.3 *High-Extension Measurements*—For making measurements at elongations greater than 20 %, measuring techniques with error no greater than ±10 % of the measured value are acceptable.

5.2.4 *Poisson's Ratio*—Bi-axial extensometer or axial and transverse extensometers capable of recording axial strain and transverse strain simultaneously. The extensometers shall be capable of measuring the change in strains with an accuracy of 1 % of the relevant value or better.

NOTE 8—Strain gages can be used as an alternative method to measure axial and transverse strain; however, proper techniques for mounting strain gages are crucial to obtaining accurate data. Consult strain gage suppliers for instruction and training in these special techniques.

5.3 *Micrometers*—Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: *(1)* a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), *(2)* a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter, and *(3)* a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.0002 in.) over the entire foot area. Flatness of the foot and anvil shall conform to Test Method D 5947.

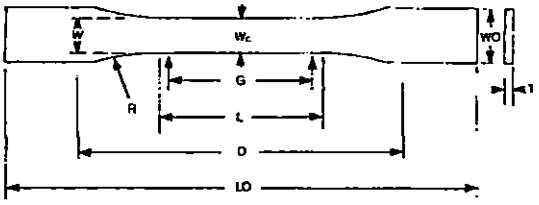
5.3.1 An optional instrument equipped with a circular contact foot 15.88 ± 0.08 mm (0.625 ± 0.003 in.) in diameter is recommended for thickness measuring of process samples or larger specimens at least 15.88 mm in minimum width.

6. Test Specimens

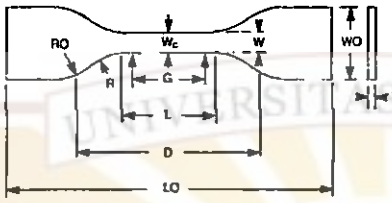
6.1 *Sheet, Plate, and Molded Plastics*:

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall



TYPES I, II, III & IV



TYPE IV

Specimen Dimensions for Thickness, *T*, mm (in.)[A]

ns (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
rrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
rrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
rall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
rall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
rall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
tween grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
let	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
us (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

T, shall be 3.2± 0.4 mm (0.13 ± 0.02 in.) for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. ominal thickness greater than 14 mm (0.55 in.) the specimens shall be machined to 14 ± 0.4 mm (0.55 ± 0.02 in.) in thickness, for use with the Type III sheets of nominal thickness between 14 and 51 mm (0.55 and 2 in.) approximately equal amounts shall be machined from each surface. For thicker sheets f the specimen shall be machined, and the location of the specimen with reference to the original thickness of the sheet shall be noted. Tolerances on han 14 mm (0.55 in.) shall be those standard for the grade of material tested.

e IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm (0.250± 0.002 in.). The dimensions are essentially those of Die ods D 412.

/ specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:
0.03 mm (0.125 ± 0.001 in.),
0.08 mm (0.375 ± 0.003 in.),
0.02 mm (0.300 ± 0.001 in.), and
0.08 mm (0.500 ± 0.003 in.).

erances are those in the table.

data on the introduction of the L specimen of Test Method D 1822 as the Type V specimen are available from ASTM Headquarters. Request RR:D20-1038.

t the center W_c shall be +0.00 mm, −0.10 mm (+0.000 in., −0.004 in.) compared with width *W* at other parts of the reduced section. Any reduction in *W* hall be gradual, equally on each side so that no abrupt changes in dimension result.

specimens, a draft of not over 0.13 mm (0.005 in.) may be allowed for either Type I or II specimens 3.2 mm (0.13 in.) in thickness, and this should be taken hen calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:

ths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

gths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

or initial extensometer span.

ghtening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if orm once chosen.

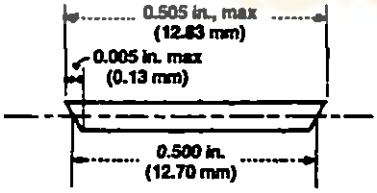


FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

testing nonrigid plastics with a thickness of 4 mm r less. The Type III specimen must be used for all ith a thickness greater than 7 mm (0.28 in.) but not 4 mm (0.55 in.).

6.1.3 *Reinforced Composites*—The test specimen for reinforced composites, including highly orthotropic laminates, shall conform to the dimensions of the Type I specimen shown in Fig. 1.

eparation—Test specimens shall be prepared by operations, or die cutting, from materials in sheet, or similar form. Materials thicker than 14 mm (0.55 e machined to 14 mm (0.55 in.) for use as Type III . Specimens can also be prepared by molding the be tested.

Test results have shown that for some materials such as glass , and BMC laminates, other specimen types should be o ensure breakage within the gage length of the specimen, as 7.3.

–When preparing specimens from certain composite lami- as woven roving, or glass cloth, care must be exercised in specimens parallel to the reinforcement. The reinforcement ificantly weakened by cutting on a bias, resulting in lower perties, unless testing of specimens in a direction other than the reinforcement constitutes a variable being studied.

–Specimens prepared by injection molding may have different erties than specimens prepared by machining or die-cutting he orientation induced. This effect may be more pronounced s with narrow sections.

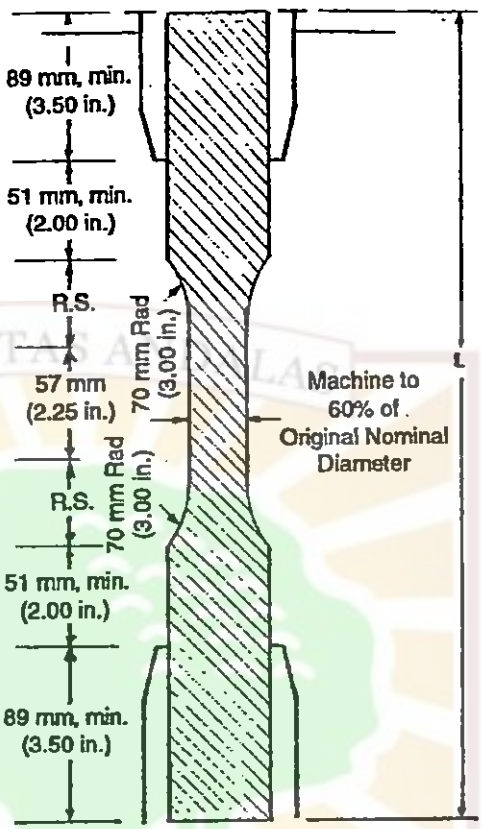
id Tubes—The test specimen for rigid tubes shall be n Fig. 2. The length, *L*, shall be as shown in the table A groove shall be machined around the outside of the t the center of its length so that the wall section after shall be 60 % of the original nominal wall thick- groove shall consist of a straight section 57.2 mm in length with a radius of 76 mm (3 in.) at each end to the outside diameter. Steel or brass plugs having such that they will fit snugly inside the tube and ength equal to the full jaw length plus 25 mm (1 in.) placed in the ends of the specimens to prevent They can be located conveniently in the tube by and supporting them on a threaded metal rod. plugs and test assembly are shown in Fig. 2.

id Rods—The test specimen for rigid rods shall be as Fig. 3. The length, *L*, shall be as shown in the table A groove shall be machined around the specimen at of its length so that the diameter of the machined all be 60 % of the original nominal diameter. This all consist of a straight section 57.2 mm (2.25 in.) in h a radius of 76 mm (3 in.) at each end joining it to e diameter.

surfaces of the specimen shall be free of visible atches, or imperfections. Marks left by coarse ma- erations shall be carefully removed with a fine file or and the filed surfaces shall then be smoothed with aper (No. 00 or finer). The finishing sanding strokes ade in a direction parallel to the long axis of the test All flash shall be removed from a molded specimen, eat care not to disturb the molded surfaces. In a specimen, undercuts that would exceed the al tolerances shown in Fig. 1 shall be scrupulously Care shall also be taken to avoid other common errors.

t is necessary to place gage marks on the specimen, be done with a wax crayon or India ink that will not material being tested. Gage marks shall not be punched, or impressed on the specimen.

en testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.



DIMENSIONS OF ROD SPECIMENS

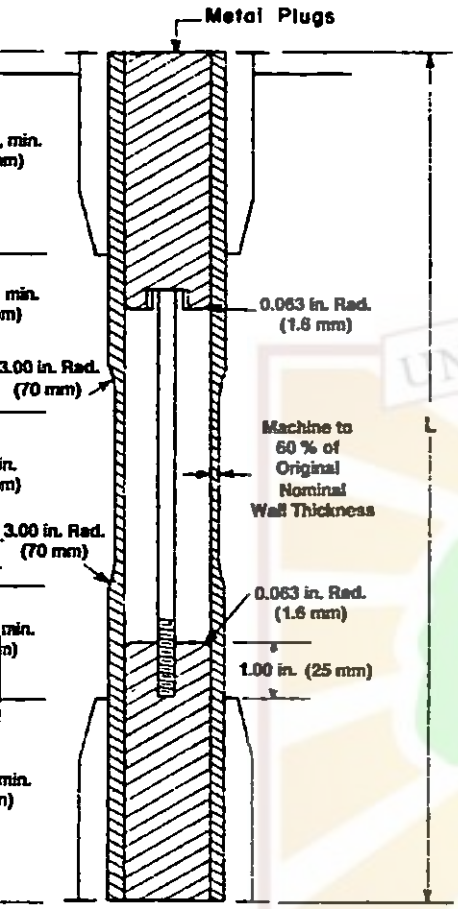
Nominal Diameter	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3½-in.) Jaws[A]
	mm (in.)		
3.2 (⅛)	19.6 (0.773)	356 (14.02)	381 (15)
4.7 (3/16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (¼)	27.7 (1.091)	364 (14.34)	381 (15)
9.5 (⅜)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (½)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (⅝)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (¾)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (⅞)	51.5 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
42.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.993)	412 (16.24)	432 (17)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 3 Diagram Showing Location of Rod Tension Test Specimen in Testing Machine

7. Number of Test Specimens

7.1 Test at least five specimens for each sample in the case of isotropic materials.



DIMENSIONS OF TUBE SPECIMENS

Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3.5-in.) Jaws[A]
mm (in.)		
13.9 (0.547)	350 (13.80)	381 (15)
17.0 (0.670)	354 (13.92)	381 (15)
19.6 (0.773)	356 (14.02)	381 (15)
24.0 (0.946)	361 (14.20)	381 (15)
27.7 (1.091)	364 (14.34)	381 (15)
33.9 (1.333)	370 (14.58)	381 (15)
39.0 (1.536)	376 (14.79)	400 (15.75)
43.5 (1.714)	380 (14.96)	400 (15.75)
47.6 (1.873)	384 (15.12)	400 (15.75)
51.3 (2.019)	388 (15.27)	400 (15.75)
54.7 (2.154)	391 (15.40)	419 (16.5)

ws greater than 89 mm (3.5 in.), the standard length shall be
ice the length of the jaws minus 178 mm (7 in.). The standard
slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each
aining the maximum length of the jaw grip.

Diagram Showing Location of Tube Tension Test Specimens in Testing Machine

ten specimens, five normal to, and five parallel
inciple axis of anisotropy, for each sample in the
otropic materials.

rd specimens that break at some flaw, or that break
the narrow cross-sectional test section (Fig. 1,
L"), and make retests, unless such flaws constitute
a variable to be studied.

NOTE 12—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

8. Speed of Testing

8.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. The rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

8.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5-min testing time.

8.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

8.4 Poisson's ratio determinations shall be made at the same speed selected for modulus determinations.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice D 618, unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

9.2 *Test Conditions*—Conduct the tests at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified by contract or the relevant ASTM material specification. Reference testing conditions, to settle disagreements,

TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min (in./min)	Nominal Strain[C] Rate at Start of Test, mm/mm· min (in./in.·min)
Rigid and Semirigid	I, II, III rods and tubes	5 (0.2) ± 25 %	0.1
		50 (2) ± 10 %	1
		500 (20) ± 10 %	10
	IV	5 (0.2) ± 25 %	0.15
		50 (2) ± 10 %	1.5
		500 (20) ± 10 %	15
	V	1 (0.05) ± 25 %	0.1
		10 (0.5) ± 25 %	1
		100 (5)± 25 %	10
Nonrigid	III	50 (2) ± 10 %	1
		500 (20) ± 10 %	10
	IV	50 (2) ± 10 %	1.5
		500 (20) ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 8.2).

[B] See Terminology D 883 for definitions.

[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

tolerances of ±1°C (1.8°F) and ±2 % relative

dure

easure the width and thickness of rigid flat speci-
1) with a suitable micrometer to the nearest 0.025
in.) at several points along their narrow sections.
e thickness of nonrigid specimens (produced by a
die) in the same manner with the required dial
r. Take the width of this specimen as the distance
e cutting edges of the die in the narrow section.
e diameter of rod specimens, and the inside and
meters of tube specimens, to the nearest 0.025 mm
at a minimum of two points 90° apart; make these
nts along the groove for specimens so constructed.
in testing tube specimens, as shown in Fig. 2.

lodulus, 10^5 psi, for Eight Laboratories, Five Materials

	Mean	S_r	S_R	I_r	I_R
	0.210	0.0089	0.071	0.025	0.201
ate butyrate	0.246	0.0179	0.035	0.051	0.144
	0.481	0.0179	0.063	0.051	0.144
ed nylon	1.17	0.0537	0.217	0.152	0.614
ed polyester	1.39	0.0894	0.266	0.253	0.753

ace the specimen in the grips of the testing machine,
to align the long axis of the specimen and the grips
aginary line joining the points of attachment of the
e machine. The distance between the ends of the
urfaces, when using flat specimens, shall be as
n Fig. 1. On tube and rod specimens, the location for
hall be as shown in Fig. 2 and Fig. 3. Tighten the
ly and firmly to the degree necessary to prevent
f the specimen during the test, but not to the point
specimen would be crushed.
tach the extension indicator. When modulus is being
l, a Class B-2 or better extensometer is required (see

—Modulus of materials is determined from the slope of the
n of the stress-strain curve. For most plastics, this linear
ry small, occurs very rapidly, and must be recorded automati-
hange in jaw separation is never to be used for calculating
elongation.

Poisson's Ratio Determination:

When Poisson's ratio is determined, the speed of
the load range at which it is determined shall be the
ose used for modulus of elasticity.

Attach the transverse strain measuring device. The
strain measuring device must continuously measure
simultaneously with the axial strain measuring

Tensile Stress at Yield, 10^3 psi, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
e	3.63	0.022	0.161	0.062	0.456
tate butyrate	5.01	0.058	0.227	0.164	0.642
	10.4	0.067	0.317	0.190	0.897

TABLE 4 Elongation at Yield, %, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Cellulose acetate butyrate	3.65	0.27	0.62	0.76	1.75
Acrylic	4.89	0.21	0.55	0.59	1.56
Polypropylene	8.79	0.45	5.86	1.27	16.5

10.3.1.3 Make simultaneous measurements of load and strain and record the data. The precision of the value of Poisson's ratio will depend on the number of data points of axial and transverse strain taken.

10.4 Set the speed of testing at the proper rate as required in Section 8, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 14—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials, to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad-range incremental extensometer or hand-rule technique may be needed when such materials are taken to rupture.

11. Calculation

11.1 Toe compensation shall be made in accordance with Annex A1, unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

11.2 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (or pounds-force) by the original minimum cross-sectional area of the specimen in square metres (or square inches). Express the result in pascals (or pounds-force per square inch) and report it to three significant figures as tensile strength at yield or tensile strength at break, whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding tensile stress at yield or tensile stress at break and report it to three significant figures (see Note A2.8).

11.3 *Percent Elongation*—If the specimen gives a yield load that is larger than the load at break, calculate percent elongation at yield. Otherwise, calculate percent elongation at break. Do this by reading the extension (change in gage length) at the moment the applicable load is reached. Divide that extension by the original gage length and multiply by 100. Report percent elongation at yield or percent elongation at break to two significant figures. When a yield or breaking load less than the maximum is present and of interest, it is desirable to calculate and report both percent elongation at yield and percent elongation at break (see Note A2.2).

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average initial cross-sectional area

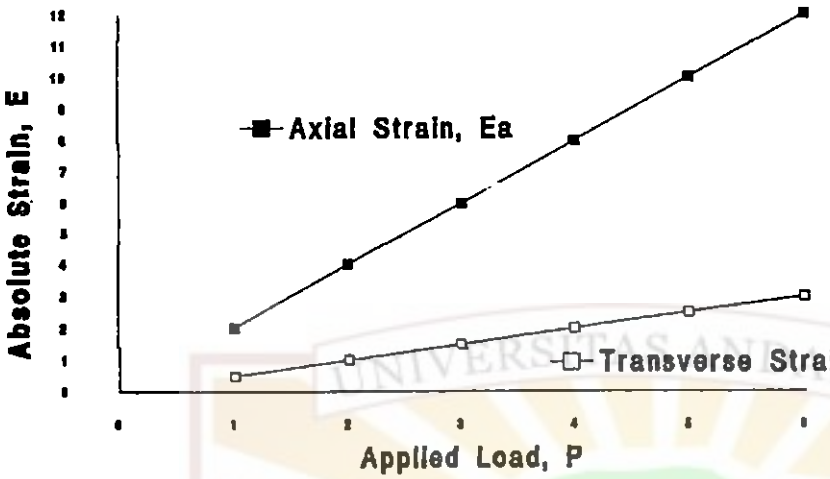


FIG. 4 Plot of Strains Versus Load for Determination of Poisson's Ratio

pecimens in the calculations. The result shall be
pascals (pounds-force per square inch) and
hree significant figures.

nt Modulus—At a designated strain, this shall be
y dividing the corresponding stress (nominal) by
d strain. Elastic modulus values are preferable and
ulated whenever possible. However, for materials
portionality is evident, the secant value shall be
raw the tangent as directed in A1.3 and Fig. A1.2,
f the designated strain from the yield point where
ine goes through zero stress. The stress to be used
lation is then determined by dividing the load-
rve by the original average cross-sectional area of
.

son's Ratio—The axial strain, ϵ_a, indicated by the
ometer, and the transverse strain, ϵ, indicated by
e extensometers, are plotted against the applied
hown in Fig. 4. A straight line is drawn through
oints, and the slopes, $d\epsilon_a / dP$ and $d\epsilon_t / dP$, of these
ermined. Poisson's ratio, μ, is then calculated as

$$\mu = -(d\epsilon_t / dP)/(d\epsilon_a / dP) \quad (1)$$

nge in transverse strain,
nge in axial strain, and
nge in applied load;

$$\mu = -(d\epsilon_t) / (d\epsilon_a) \quad (2)$$

e errors that may be introduced by drawing a
through the points can be reduced by applying the
ast squares.

each series of tests, calculate the arithmetic mean
obtained and report it as the "average value" for
r property in question.

ulate the standard deviation (estimated) as follows
to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2) / (n - 1)} \quad (3)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

11.9 See Annex A1 for information on toe compensation.

TABLE 5 Tensile Strength at Break, 10^3 psi, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Polypropylene	2.97	1.54	1.65	4.37	4.66
Cellulose acetate butyrate	4.82	0.058	0.180	0.164	0.509
Acrylic	9.09	0.452	0.751	1.27	2.13
Glass-reinforced polyester	20.8	0.233	0.437	0.659	1.24
Glass-reinforced nylon	23.6	0.277	0.698	0.784	1.98

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

TABLE 6 Elongation at Break, %, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Glass-reinforced polyester	3.68	0.20	2.33	0.570	6.59
Glass-reinforced nylon	3.87	0.10	2.13	0.283	6.03
Acrylic	13.2	2.05	3.65	5.80	10.3
Cellulose acetate butyrate	14.1	1.87	6.62	5.29	18.7
Polypropylene	293.0	50.9	119.0	144.0	337.0

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

Tensile Yield Strength, for Ten Laboratories, Eight Materials

Test Speed, in./min	Values Expressed in psi Units				
	Average	S_r	S_R	r	R
20	1544	52.4	64.0	146.6	179.3
20	1894	53.1	61.2	148.7	171.3
20	1879	74.2	99.9	207.8	279.7
20	1791	49.2	75.8	137.9	212.3
20	2900	55.5	87.9	155.4	246.1
20	1730	63.9	96.0	178.9	268.7
2	4101	186.1	371.9	549.1	1041.3
2	3523	175.9	478.0	492.4	1338.5

Conditioning procedure used,
Atmospheric conditions in test room,
Number of specimens tested,
Speed of testing,
Classification of extensometers used. A description ng technique and calculations employed instead of a Class-C extensometer system,
Tensile strength at yield or break, average value, and eviation,
Tensile stress at yield or break, if applicable, lue, and standard deviation,
Percent elongation at yield or break, or both, as average value, and standard deviation,
Modulus of elasticity, average value, and standard

Date of test, and
Revision date of Test Method D 638.

ion and Bias [12]

ecision—Tables 2-6 are based on a round-robin test in 1984, involving five materials tested by eight s using the Type I specimen, all of nominal 0.125-in. Each test result was based on five individual ions. Each laboratory obtained two test results for rial.

Tensile Yield Elongation, for Eight Laboratories, Eight Materials

Test Speed, in./min	Values Expressed in Percent Units				
	Average	S_r	S_R	r	R
20	17.0	1.26	3.16	3.52	8.84
20	14.6	1.02	2.38	2.86	6.67
20	15.7	1.37	2.85	3.85	7.97
20	16.6	1.59	3.30	4.46	9.24
20	11.7	1.27	2.88	3.56	8.08
20	15.2	1.27	2.59	3.55	7.25
2	9.27	1.40	2.84	3.91	7.94
2	9.63	1.23	2.75	3.45	7.71

Tables 7-10 are based on a round-robin test con- the polyolefin subcommittee in 1988, involving eight ne materials tested in ten laboratories. For each all samples were molded at one source, but the

ing data are available from ASTM Headquarters. Request RR:D20-1984 round robin and RR:D20-1170 for the 1988 round robin.

TABLE 9 Tensile Break Strength, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1592	52.3	74.9	146.4	209.7
LDPE	20	1750	66.6	102.9	186.4	288.1
LLDPE	20	4379	127.1	219.0	355.8	613.3
LLDPE	20	2840	78.6	143.5	220.2	401.8
LLDPE	20	1679	34.3	47.0	95.96	131.6
LLDPE	20	2660	119.1	166.3	333.6	465.6

TABLE 10 Tensile Break Elongation, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	567	31.5	59.5	88.2	166.6
LDPE	20	569	61.5	89.2	172.3	249.7
LLDPE	20	890	25.7	113.8	71.9	318.7
LLDPE	20	64.4	6.68	11.7	18.7	32.6
LLDPE	20	803	25.7	104.4	71.9	292.5
LLDPE	20	782	41.6	96.7	116.6	270.8

individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material. Data from some laboratories could not be used for various reasons, and this is noted in each table.

13.1.2 In Tables 2-10, for the materials indicated, and for test results that derived from testing five specimens:

13.1.2.1 S_r is the within-laboratory standard deviation of the average; $I_r = 2.83\ S_r$. (See 13.1.2.3 for application of I_r.)

13.1.2.2 S_R is the between-laboratory standard deviation of the average; $I_R = 2.83\ S_R$. (See 13.1.2.4 for application of I_R.)

13.1.2.3 *Repeatability*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, those test results should be judged not equivalent if they differ by more than the I_r value for that material and condition.

13.1.2.4 *Reproducibility*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, those test results should be judged not equivalent if they differ by more than the I_R value for that material and condition. (This applies between different laboratories or between different equipment within the same laboratory.)

13.1.2.5 Any judgment in accordance with 13.1.2.3 and 13.1.2.4 will have an approximate 95 % (0.95) probability of being correct.

13.1.2.6 Other formulations may give somewhat different results.

13.1.2.7 For further information on the methodology used in this section, see Practice E 691.

13.1.2.8 The precision of this test method is very dependent upon the uniformity of specimen preparation, standard practices for which are covered in other documents.

13.2 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

s

us of elasticity; percent elongation; plastics;
ies; tensile strength

ANNEXES

(Mandatory Information)

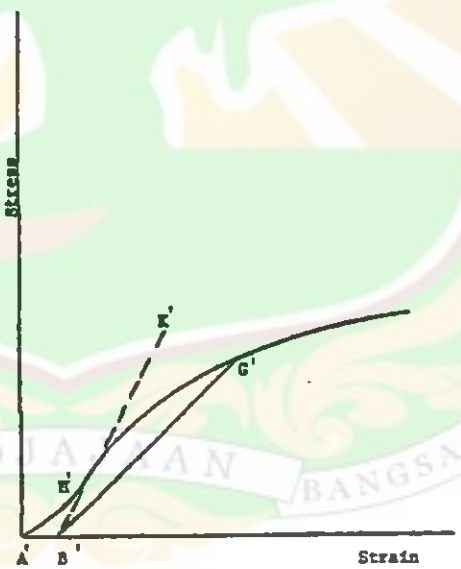
A1. TOE COMPENSATION

typical stress-strain curve (Fig. A1.1) there is a *C*, that does not represent a property of the an artifact caused by a takeup of slack and eating of the specimen. In order to obtain correct parameters as modulus, strain, and offset yield tifact must be compensated for to give the point on the strain or extension axis.

he case of a material exhibiting a region of ar) behavior (Fig. A1.1), a continuation of the egion of the curve is constructed through the is. This intersection (*B*) is the corrected zero- rom which all extensions or strains must be luding the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from Point *B*, defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H'*). This is extended to intersect the strain axis at Point *B'*, the corrected zero-strain point. Using Point *B'* as zero strain, the stress at any point (*G'*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B' G'*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.

me chart recorders plot the mirror image of this graph.
IG. A1.1 Material with Hookean Region



NOTE 1—Some chart recorders plot the mirror image of this graph.
FIG. A1.2 Material with No Hookean Region

A2. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

astic limit—the greatest stress which a material is sustaining without any permanent strain remaining ete release of the stress. It is expressed in force per sually pounds-force per square inch (megapascals).

—Measured values of proportional limit and elastic limit with the sensitivity and accuracy of the testing equipment, f loading, the scale to which the stress-strain diagram is ther factors. Consequently, these values are usually replaced gth.

ongation—the increase in length produced in the n of the test specimen by a tensile load. It is n units of length, usually inches (millimetres). (Also *xtension*.)

—Elongation and strain values are valid only in cases where specimen behavior within the gage length is present. In the ials exhibiting necking phenomena, such values are only of lity after attainment of yield point. This is due to inability to ecking will encompass the entire length between the gage o specimen failure.

ge length—the original length of that portion of the ver which strain or change in length is determined.

odulus of elasticity—the ratio of stress (nominal) to ing strain below the proportional limit of a material. ssed in force per unit area, usually megapascals rce per square inch). (Also known as *elastic modu-g's modulus*).

—The stress-strain relations of many plastics do not con-ke's law throughout the elastic range but deviate therefrom es well below the elastic limit. For such materials the slope t to the stress-strain curve at a low stress is usually taken as of elasticity. Since the existence of a true proportional limit debatable, the propriety of applying the term "modulus of describe the stiffness or rigidity of a plastic has been estioned. The exact stress-strain characteristics of plastic very dependent on such factors as rate of stressing, previous specimen history, etc. However, such a value is arbitrary nature and dependence on time, temperature, and are realized.

ecking—the localized reduction in cross section occur in a material under tensile stress.

ffset yield strength—the stress at which the strain a specified amount (the offset) an extension of the portional portion of the stress-strain curve. It is n force per unit area, usually megapascals (pounds-quare inch).

—This measurement is useful for materials whose stress-in the yield range is of gradual curvature. The offset yield be derived from a stress-strain curve as follows (Fig. A2.1):

ain axis lay off *OM* equal to the specified offset.
tangent to the initial straight-line portion of the stress-strain

f draw a line *MN* parallel to *OA* and locate the intersection of stress-strain curve.

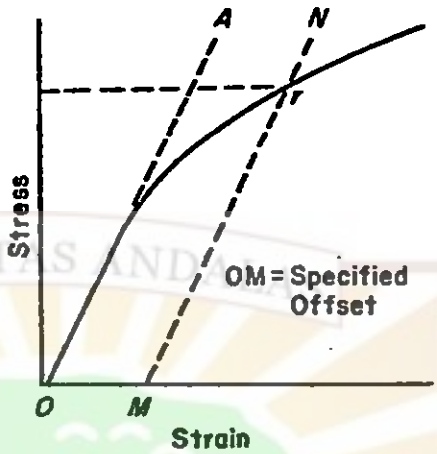


FIG. A2.1 Offset Yield Strength

The stress at the point of intersection *r* is the "offset yield strength." The specified value of the offset must be stated as a percent of the original gage length in conjunction with the strength value. *Example:* 0.1 % offset yield strength = ... MPa (psi), or yield strength at 0.1 % offset ... MPa (psi).

A2.7 *percent elongation*—the elongation of a test specimen expressed as a percent of the gage length.

A2.8 *percent elongation at break and yield:*

A2.8.1 *percent elongation at break*
the percent elongation at the moment of rupture of the test specimen.

A2.8.2 *percent elongation at yield*
the percent elongation at the moment the yield point (A2.21) is attained in the test specimen.

A2.9 *percent reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percent of the original area.

A2.10 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A2.11 *proportional limit*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

A2.12 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons (pounds-force) per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A2.13 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually

metre (inches per inch) per minute, or percent
er unit time, usually percent elongation per minute.
ate of straining can be calculated from the initial
tensile strain versus time diagram.

–The initial rate of straining is synonymous with the rate of
ement divided by the initial distance between crossheads
ine with constant rate of crosshead movement and when the
uniform original cross section, does not "neck down," and
n the jaws.

te of stressing (nominal)—the change in tensile
nal) per unit time. It is expressed in force per unit
it time, usually megapascals (pounds-force per
per minute. The initial rate of stressing can be
om the initial slope of the tensile stress (nominal)
diagram.

–The initial rate of stressing as determined in this manner
d physical significance. It does, however, roughly describe
te at which the initial stress (nominal) carried by the test
plied. It is affected by the elasticity and flow characteristics
s being tested. At the yield point, the rate of stressing (true)
to have a positive value if the cross-sectional area is

cant modulus—the ratio of stress (nominal) to
g strain at any specified point on the stress-strain
xpressed in force per unit area, usually megapas-
-force per square inch), and reported together with
stress or strain.

–This measurement is usually employed in place of modu-
y in the case of materials whose stress-strain diagram does
e proportionality of stress to strain.

rain—the ratio of the elongation to the gage length
pecimen, that is, the change in length per unit of
th. It is expressed as a dimensionless ratio.

nsile strength (nominal)—the maximum tensile
nal) sustained by the specimen during a tension
the maximum stress occurs at the yield point
hall be designated tensile strength at yield. When
m stress occurs at break, it shall be designated
gth at break.

nsile stress (nominal)—the tensile load per unit
imum original cross section, within the gage
carried by the test specimen at any given moment.
sed in force per unit area, usually megapascals
e per square inch).

–The expression of tensile properties in terms of the
inal cross section is almost universally used in practice. In
aterials exhibiting high extensibility or necking, or both
nal stress calculations may not be meaningful beyond the
2.21) due to the extensive reduction in cross-sectional area
nder some circumstances it may be desirable to express the
ies per unit of minimum prevailing cross section. These
called true tensile properties (that is, true tensile stress, etc.).

nsile stress-strain curve—a diagram in which
nsile stress are plotted as ordinates against corre-
lues of tensile strain as abscissas.

ue strain (see Fig. A2.2) is defined by the follow-
for ϵ_T:

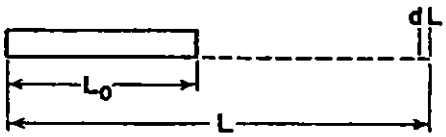


FIG. A2.2 Illustration of True Strain Equation

$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o \qquad \text{(A2.1)}$$

where:

dL = increment of elongation when the distance between the gage marks is L,
L_o = original distance between gage marks, and
L = distance between gage marks at any time.

A2.21 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A2.2).

NOTE A2.9—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

NOTE A2.10—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A2.22 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the tensile strength shall be designated either tensile strength at yield or tensile stress at yield as required in A2.17 (Fig. A2.3). (See *offset yield strength.*)

A2.23 *Symbols*—The following symbols may be used for the above terms:

Symbol	Term
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_U	Tensile strength at break (nominal)
σ_{UT}	Tensile strength at break (true)
ϵ	Strain
$\Delta\epsilon$	Increment of strain
ϵ_U	Total strain, at break
ϵ_T	True strain
%*El*	Percentage elongation
Y.P.	Yield point
E	Modulus of elasticity

A2.24 Relations between these various terms may be defined as follows:

σ_U = W/A_o (where W is breaking load)
σ_{UT} = W/A_T (where W is breaking load)
ϵ = $\Delta L/L_o = (L - L_o)/L_o$
ϵ_U = $(L_u - L_o)/L_o$
ϵ_T = $\int_{L_o}^{L} dL/L = \ln L/L_o$
%EI = $[(L - L_o)/L_o] \times 100 = \epsilon \times 100$

Percent reduction of area (nominal) = $[(A_o - A_u)/A_o] \times 100$
Percent reduction of area (true) = $[(A_o - A_T)/A_o] \times 100$
Rate of loading = $\Delta W/\Delta t$
Rate of stressing (nominal) = $\Delta\sigma/\Delta = (\Delta W/A_o)/\Delta t$
Rate of straining = $\Delta\epsilon/\Delta t = (\Delta L/L_o)\Delta t$

For the case where the volume of the test specimen does not change during the test, the following three relations hold:

$$\sigma_T = \sigma(1 + \epsilon) = \sigma L/L_o \quad \text{(A2.2)}$$
$$\sigma_{UT} = \sigma_U(1 + \epsilon_U) = \sigma_U L_u/L_o$$
$$A = A_o/(1 + \epsilon)$$

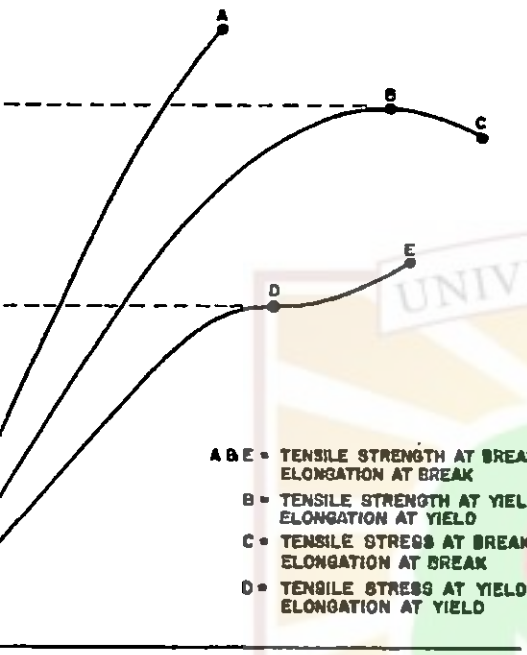


FIG. A2.3 Tensile Designations

= W/A_o
= W/A

SUMMARY OF CHANGES

This section identifies the location of selected changes to this test method. For the convenience of the user, ommittee D20 has highlighted those changes that may impact the use of this test method. This section may also clude descriptions of the changes or reasons for the changes, or both.

d 9.1 and 9.2.

ed 7.3 regarding conditions for specimen discard.

11.1 and renumbered subsequent sections.

and clarified extensometer classification require-

D 638–98:

(*1*) Revised 10.3 and added 12.1.8 to clarify extensometer usage.

(*2*) Added 12.1.14.

(*3*) Replaced reference to Test Methods D 374 with Test Method D 5947 in 2.1 and 5.3.

Designation: D 790 – 02

An American National Standard

Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[1]

This standard is issued under the fixed designation D 790; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

se test methods cover the determination of flexural of unreinforced and reinforced plastics, including ılus composites and electrical insulating materials in f rectangular bars molded directly or cut from sheets, molded shapes. These test methods are generally to both rigid and semirigid materials. However, rength cannot be determined for those materials that ak or that do not fail in the outer surface of the test within the 5.0 % strain limit of these test methods. methods utilize a three-point loading system applied ly supported beam. A four-point loading system n be found in Test Method D 6272.

rocedure A, designed principally for materials that omparatively small deflections.

rocedure B, designed particularly for those materials go large deflections during testing.

rocedure A shall be used for measurement of flexural particularly flexural modulus, unless the material on states otherwise. Procedure B may be used for ent of flexural strength only. Tangent modulus data by Procedure A tends to exhibit lower standard than comparable data obtained by means of Proce-

nparative tests may be run in accordance with either provided that the procedure is found satisfactory for al being tested.

values stated in SI units are to be regarded as the The values provided in parentheses are for informa-

s standard does not purport to address all of the ncerns, if any, associated with its use. It is the lity of the user of this standard to establish appro- ety and health practices and determine the applica- gulatory limitations prior to use.

These test methods are not technically equivalent to ISO 178.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 883 Terminology Relating to Plastics[2]

D 4000 Classification System for Specifying Plastic Materials[3]

D 5947 Test Methods for Physical Dimensions of Solid Plastic Specimens[4]

D 6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending[4]

E 4 Practices for Force Verification of Testing Machines[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

3. Terminology

3.1 *Definitions*—Definitions of terms applying to these test methods appear in Terminology D 883 and Annex A1 of Test Method D 638.

4. Summary of Test Method

4.1 A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1). A support span-to-depth ratio of 16:1 shall be used unless there is reason to suspect that a larger span-to-depth ratio may be required, as may be the case for certain laminated materials (see Section 7 and Note 8 for guidance).

4.2 The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain (see 12.7) of 5.0 % is reached, whichever occurs first.

4.3 Procedure A employs a strain rate of 0.01 mm/mm/min (0.01 in./in./min) and is the preferred procedure for this test method, while Procedure B employs a strain rate of 0.10 mm/mm/min (0.10 in./in./min).

st methods are under the jurisdiction of ASTM Committee D20 on ure the direct responsibility of Subcommittee D20.10 on Mechanical

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[2] *Annual Book of ASTM Standards*, Vol 08.01.
[3] *Annual Book of ASTM Standards*, Vol 08.02.
[4] *Annual Book of ASTM Standards*, Vol 08.03.
[5] *Annual Book of ASTM Standards*, Vol 03.01.
[6] *Annual Book of ASTM Standards*, Vol 14.02.

***A Summary of Changes section appears at the end of this standard.**

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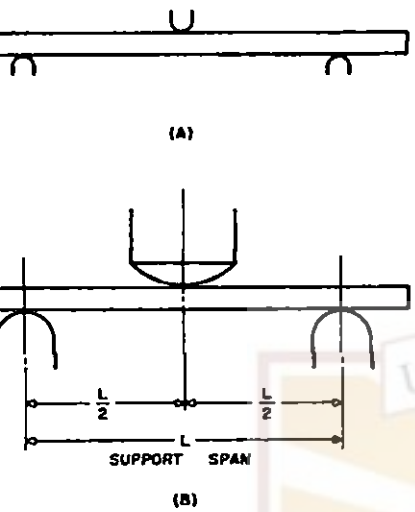


Minimum radius = 3.2 mm (⅛ in.). (*b*) Maximum radius mes specimen depth; maximum radius loading nose = 4 depth.

owable Range of Loading Nose and Support Radii

TABLE 1 Flexural Strength

Material	Mean, 10^3 psi	Values Expressed in Units of % of 10^3 psi			
		V_r[A]	V_R[B]	r[C]	R[D]
ABS	9.99	1.59	6.05	4.44	17.2
DAP thermoset	14.3	6.58	6.58	18.6	18.6
Cast acrylic	16.3	1.67	11.3	4.73	32.0
GR polyester	19.5	1.43	2.14	4.05	6.08
GR polycarbonate	21.0	5.16	6.05	14.6	17.1
SMC	26.0	4.76	7.19	13.5	20.4

[A] V_r = within-laboratory coefficient of variation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all of the participating laboratories: $Sr = [[(s_1)^2 + (s_2)^2 \ldots + (s_n)^2]/n]^{1/2}$ then V_r = (S_r divided by the overall average for the material) × 100.

[B] V_r = between-laboratory reproducibility, expressed as the coefficient of variation: $S_R = \{S_r^2 + S_L^2\}^{1/2}$ where S_L is the standard deviation of laboratory means. Then: V_R = (S_R divided by the overall average for the material) × 100.

[C] r = within-laboratory critical interval between two test results = 2.8 × V_r.

[D] R = between-laboratory critical interval between two test results = 2.8 × V_R.

ace and Use

al properties as determined by these test methods ly useful for quality control and specification

ials that do not fail by the maximum strain er these test methods (3-point bend) may be more -point bend test. The basic difference between the hods is in the location of the maximum bending maximum axial fiber stresses. The maximum axial occur on a line under the loading nose in 3-point over the area between the loading noses in 4-point

al properties may vary with specimen depth, atmospheric conditions, and the difference in rate as specified in Procedures A and B (see also Note

e proceeding with these test methods, reference ade to the specification of the material being tested. ecimen preparation, conditioning, dimensions, or meters, or combination thereof, covered in the ecification shall take precedence over those men- se test methods. If there are no material specifi- the default conditions apply. Table 1 in Classifi- n D 4000 lists the ASTM materials standards that st for plastics.

us

g Machine— A properly calibrated testing ma- n be operated at constant rates of crosshead motion ge indicated, and in which the error in the load ystem shall not exceed ±1 % of the maximum load be measured. It shall be equipped with a deflection evice. The stiffness of the testing machine shall be e total elastic deformation of the system does not of the total deflection of the test specimen during testing, or appropriate corrections shall be made. The load indicating mechanism shall be essentially free from inertial lag at the crosshead rate used. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

6.2 *Loading Noses and Supports*—The loading nose and supports shall have cylindrical surfaces. In order to avoid excessive indentation, or failure due to stress concentration directly under the loading nose, the radii of the loading nose and supports shall be 5.0 ± 0.1 mm (0.197 ± 0.004 in.) unless otherwise specified or agreed upon between the interested clients. When other loading noses and supports are used they must comply with the following requirements: they shall have a minimum radius of 3.2 mm (⅛ in.) for all specimens, and for specimens 3.2 mm or greater in depth, the radius of the supports may be up to 1.6 times the specimen depth. They shall be this large if significant indentation or compressive failure occurs. The arc of the loading nose in contact with the specimen shall be sufficiently large to prevent contact of the specimen with the sides of the nose (see Fig. 1). The maximum radius of the loading nose shall be no more than 4 times the specimen depth.

NOTE 2—Test data have shown that the loading nose and support dimensions can influence the flexural modulus and flexural strength values. The loading nose dimension has the greater influence. Dimensions of the loading nose and supports must be specified in the material specification.

6.3 *Micrometers*— Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter and a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.002 in.) over the entire foot area. Flatness of foot and anvil shall conform to the portion of the Calibration section of Test Methods D 5947.

7. Test Specimens

7.1 The specimens may be cut from sheets, plates, or

apes, or may be molded to the desired finished
. The actual dimensions used in Section 4.2, Cal-
aall be measured in accordance with Test Methods

Any necessary polishing of specimens shall be done only in
se direction of the specimen.

*t Materials (Except Laminated Thermosetting Ma-
Certain Materials Used for Electrical Insulation,
Vulcanized Fiber and Glass Bonded Mica)*:
aterials 1.6 mm (1/16 in.) or Greater in Thickness—
se tests, the depth of the specimen shall be the
f the material. For edgewise tests, the width of the
hall be the thickness of the sheet, and the depth shall
the width (see Notes 4 and 5). For all tests, the
an shall be 16 (tolerance ±1) times the depth of the
cimen width shall not exceed one fourth of the
an for specimens greater than 3.2 mm (⅛ in.) in
cimens 3.2 mm or less in depth shall be 12.7 mm (½
h. The specimen shall be long enough to allow for
g on each end of at least 10 % of the support span,
ase less than 6.4 mm (¼ in.) on each end. Overhang
ufficient to prevent the specimen from slipping
e supports.

Whenever possible, the original surface of the sheet shall be
owever, where testing machine limitations make it impossible
above criterion on the unaltered sheet, one or both surfaces
hined to provide the desired dimensions, and the location of
s with reference to the total depth shall be noted. The value
specimens with machined surfaces may differ from those
specimens with original surfaces. Consequently, any specifi-
lexural properties on thicker sheets must state whether the
aces are to be retained or not. When only one surface was
must be stated whether the machined surface was on the
ompression side of the beam.

Edgewise tests are not applicable for sheets that are so thin
ns meeting these requirements cannot be cut. If specimen
ls the width, buckling may occur.

aterials Less than 1.6 mm (1/16 in.) in Thickness—
nen shall be 50.8 mm (2 in.) long by 12.7 mm (½ in.)
d flatwise on a 25.4-mm (1-in.) support span.

Use of the formulas for simple beams cited in these test
calculating results presumes that beam width is small in
with the support span. Therefore, the formulas do not apply
these dimensions.

Where machine sensitivity is such that specimens of these
cannot be measured, wider specimens or shorter support
h, may be used, provided the support span-to-depth ratio is at
All dimensions must be stated in the report (see also Note 6).

*inated Thermosetting Materials and Sheet and
terials Used for Electrical Insulation, Including
Fiber and Glass-Bonded Mica*—For paper-base
-base grades over 25.4 mm (1 in.) in nominal
the specimens shall be machined on both surfaces to
25.4 mm. For glass-base and nylon-base grades,
over 12.7 mm (½ in.) in nominal depth shall be
on both surfaces to a depth of 12.7 mm. The support
pth ratio shall be chosen such that failures occur in
fibers of the specimens, due only to the bending
ee Note 8). Therefore, a ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). When laminated materials exhibit low compressive strength perpendicular to the laminations, they shall be loaded with a large radius loading nose (up to four times the specimen depth to prevent premature damage to the outer fibers.

7.4 *Molding Materials (Thermoplastics and Thermosets)*—The recommended specimen for molding materials is 127 by 12.7 by 3.2 mm (5 by ½by ⅛ in.) tested flatwise on a support span, resulting in a support span-to-depth ratio of 16 (tolerance ±1). Thicker specimens should be avoided if they exhibit significant shrink marks or bubbles when molded.

7.5 *High-Strength Reinforced Composites, Including Highly Orthotropic Laminates*—The span-to-depth ratio shall be chosen such that failure occurs in the outer fibers of the specimens and is due only to the bending moment (see Note 8). A span-to-depth ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). For some highly anisotropic composites, shear deformation can significantly influence modulus measurements, even at span-to-depth ratios as high as 40:1. Hence, for these materials, an increase in the span-to-depth ratio to 60:1 is recommended to eliminate shear effects when modulus data are required, it should also be noted that the flexural modulus of highly anisotropic laminates is a strong function of ply-stacking sequence and will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

NOTE 8—As a general rule, support span-to-depth ratios of 16:1 are satisfactory when the ratio of the tensile strength to shear strength is less than 8 to 1, but the support span-to-depth ratio must be increased for composite laminates having relatively low shear strength in the plane of the laminate and relatively high tensile strength parallel to the support span.

8. Number of Test Specimens

8.1 Test at least five specimens for each sample in the case of isotropic materials or molded specimens.

8.2 For each sample of anisotropic material in sheet form, test at least five specimens for each of the following conditions. Recommended conditions are flatwise and edgewise tests on specimens cut in lengthwise and crosswise directions of the sheet. For the purposes of this test, "lengthwise" designates the principal axis of anisotropy and shall be interpreted to mean the direction of the sheet known to be stronger in flexure. "Crosswise" indicates the sheet direction known to be the weaker in flexure and shall be at 90° to the lengthwise direction.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice D 618 unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

9.2 *Test Conditions*—Conduct the tests at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity unless otherwise specified by contract or the relevant ASTM material specification. Reference testing conditions, to settle disagreements,

olerances of ±1°C (1.8°F) and ±2 % relative

e

dure A:

an untested specimen for each measurement. width and depth of the specimen to the nearest 001 in.) at the center of the support span. For s than 2.54 mm (0.100 in.) in depth, measure the nearest 0.003 mm (0.0005 in.). These measure- e made in accordance with Test Methods D 5947. ermine the support span to be used as described in d set the support span to within 1 % of the alue.

flexural fixtures that have continuously adjust- easure the span accurately to the nearest 0.1 mm spans less than 63 mm (2.5 in.) and to the nearest 2 in.) for spans greater than or equal to 63 mm the actual measured span for all calculations. For es that have fixed machined span positions, verify ance the same as for adjustable spans at each sition. This distance becomes the span for that is used for calculations applicable to all subse- onducted at that position. See Annex A2 for n the determination of and setting of the span.

culate the rate of crosshead motion as follows and ne for the rate of crosshead motion as calculated

$$R = ZL^2/6d \quad (1)$$

crosshead motion, mm (in.)/min,
t span, mm (in.),
of beam, mm (in.), and
straining of the outer fiber, mm/mm/min (in./ n). Z shall be equal to 0.01.

shall the actual crosshead rate differ from that ing Eq 1, by more than ±10 %.

gn the loading nose and supports so that the axes ical surfaces are parallel and the loading nose is een the supports. The parallelism of the apparatus ed by means of a plate with parallel grooves into ading nose and supports will fit when properly A2.3). Center the specimen on the supports, with of the specimen perpendicular to the loading nose

ply the load to the specimen at the specified te, and take simultaneous load-deflection data. ection either by a gage under the specimen in t at the center of the support span, the gage being ionary relative to the specimen supports, or by of the motion of the loading nose relative to the d-deflection curves may be plotted to determine trength, chord or secant modulus or the tangent lasticity, and the total work as measured by the e load-deflection curve. Perform the necessary toe (see Annex A1) to correct for seating and f the specimen and deflections in the machine.

minate the test when the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm (in./in.) or at break if break occurs prior to reaching the maximum strain (Notes 9 and 10). The deflection at which this strain will occur may be calculated by letting r equal 0.05 mm/mm (in./in.) in Eq 2:

$$D = rL^2/6d \quad (2)$$

where:

D = midspan deflection, mm (in.),
r = strain, mm/mm (in./in.),
L = support span, mm (in.), and
d = depth of beam, mm (in.).

NOTE 9—For some materials that do not yield or break within the 5 % strain limit when tested by Procedure A, the increased strain rate allowed by Procedure B (see 10.2) may induce the specimen to yield or break, or both, within the required 5 % strain limit.

NOTE 10—Beyond 5 % strain, this test method is not applicable. Some other mechanical property might be more relevant to characterize materials that neither yield nor break by either Procedure A or Procedure B within the 5 % strain limit (for example, Test Method D 638 may be considered).

10.2 *Procedure B*:

10.2.1 Use an untested specimen for each measurement.

10.2.2 Test conditions shall be identical to those described in 10.1, except that the rate of straining of the outer surface of the test specimen shall be 0.10 mm/mm (in./in.)/min.

10.2.3 If no break has occurred in the specimen by the time the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm (in./in.), discontinue the test (see Note 10).

11. Retests

11.1 Values for properties at rupture shall not be calculated for any specimen that breaks at some obvious, fortuitous flaw, unless such flaws constitute a variable being studied. Retests shall be made for any specimen on which values are not calculated.

12. Calculation

12.1 Toe compensation shall be made in accordance with Annex A1 unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

12.2 *Flexural Stress* (σ_f)—When a homogeneous elastic material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress in the outer surface of the test specimen occurs at the midpoint. This stress may be calculated for any point on the load-deflection curve by means of the following equation (see Notes 11-13):

$$\sigma_f = 3PL/2bd^2 \quad (3)$$

where:

σ = stress in the outer fibers at midpoint, MPa (psi),
P = load at a given point on the load-deflection curve, N (lbf),
L = support span, mm (in.),
b = width of beam tested, mm (in.), and

th of beam tested, mm (in.).

-Eq 3 applies strictly to materials for which stress is linearly to strain up to the point of rupture and for which the strains Since this is not always the case, a slight error will be Eq 3 is used to calculate stress for materials that are not true terials. The equation is valid for obtaining comparison data ification purposes, but only up to a maximum fiber strain of uter surface of the test specimen for specimens tested by the lescribed herein.

-When testing highly orthotropic laminates, the maximum ot always occur in the outer surface of the test specimen.[7] eam theory must be applied to determine the maximum at failure. If Eq 3 is used to calculate stress, it will yield an ength based on homogeneous beam theory. This apparent highly dependent on the ply-stacking sequence of highly aminates.

-The preceding calculation is not valid if the specimen slips between the supports.

exural Stress for Beams Tested at Large Support)—If support span-to-depth ratios greater than 16 to 1 such that deflections in excess of 10 % of the an occur, the stress in the outer surface of the for a simple beam can be reasonably approximated llowing equation (see Note 14):

$$\sigma_f = (3PL/2bd^2)[1 + 6(D/L)^2 - 4(d/L)(D/L)] \quad (4)$$

b, and d are the same as for Eq 3, and ection of the centerline of the specimen at the the support span, mm (in.).

-When large support span-to-depth ratios are used, significant are developed at the support noses which will affect the a simple supported beam. Eq 4 includes additional terms that ximate correction factor for the influence of these end forces port span-to-depth ratio beams where relatively large deflec-

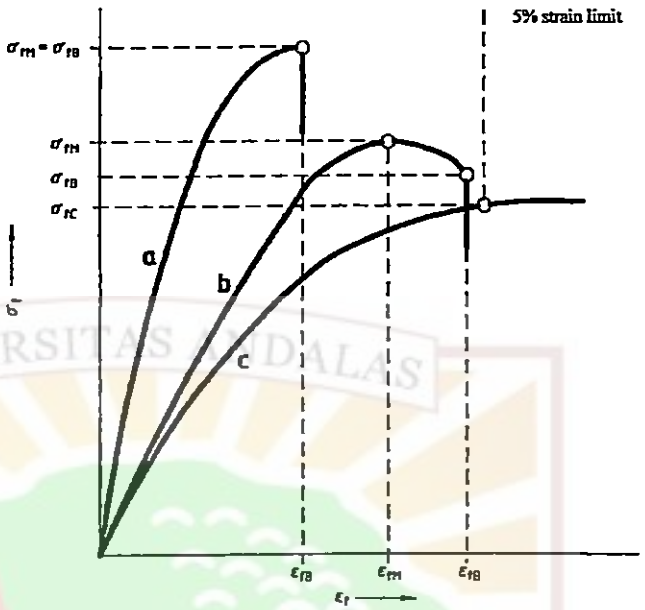
exural Strength (σ_{fM})—Maximum flexural stress by the test specimen (see Note 12) during a bending alculated according to Eq 3 or Eq 4. Some materials ot break at strains of up to 5 % may give a load curve that shows a point at which the load does not ith an increase in strain, that is, a yield point (Fig. 2, *Y*. The flexural strength may be calculated for these by letting P (in Eq 3 or Eq 4) equal this point, *Y*.

exural Offset Yield Strength—Offset yield strength is at which the stress-strain curve deviates by a given set) from the tangent to the initial straight line portion ss-strain curve. The value of the offset must be given this property is calculated.

—This value may differ from flexural strength defined in 12.4. ds of calculation are described in the annex to Test Method

exural Stress at Break (σ_{fB})—Flexural stress at ie test specimen during a bending test. It is calculated

cussion of these effects, see Zweben, C., Smith, W. S., and Wardle, M. ethods for Fiber Tensile Strength, Composite Flexural Modulus and Fabric-Reinforced Laminates, " *Composite Materials: Testing and Conference), ASTM STP 674*, 1979, pp. 228–262.



NOTE—Curve a: Specimen that breaks before yielding.
Curve b: Specimen that yields and then breaks before the 5 % strain limit.
Curve c: Specimen that neither yields nor breaks before the 5 % strain limit.

FIG. 2 Typical Curves of Flexural Stress (s_f) Versus Flexural Strain (ϵ_f)

according to Eq 3 or Eq 4. Some materials may give a load deflection curve that shows a break point, *B*, without a yield point (Fig. 2, Curve a) in which case $\sigma_{fB} = \sigma_{fM}$. Other materials may give a yield deflection curve with both a yield and a break point, *B* (Fig. 2, Curve b). The flexural stress at break may be calculated for these materials by letting P (in Eq 3 or Eq 4) equal this point, *B*.

12.7 *Stress at a Given Strain*—The stress in the outer surface of a test specimen at a given strain may be calculated in accordance with Eq 3 or Eq 4 by letting P equal the load read from the load-deflection curve at the deflection corresponding to the desired strain (for highly orthotropic laminates, see Note 12).

12.8 *Flexural Strain*, ϵ_f—Nominal fractional change in the length of an element of the outer surface of the test specimen at midspan, where the maximum strain occurs. It may be calculated for any deflection using Eq 5:

$$\epsilon_f = 6Dd/L^2 \quad (5)$$

where:

ϵ_f = strain in the outer surface, mm/mm (in./in.),
D = maximum deflection of the center of the beam, mm (in.),
L = support span, mm (in.), and
d = depth, mm (in.).
D = maximum deflection of the center of the beam, mm (in.),
L = support span, mm (in.), and

mm (in.).
lus of Elasticity:
gent Modulus of Elasticity—The tangent modu-
y, often called the "modulus of elasticity," is the
he elastic limit, of stress to corresponding strain.
ed by drawing a tangent to the steepest initial
ortion of the load-deflection curve and using Eq
anisotropic composites, see Note 16).

$$E_B = L^3m/4bd^3 \quad (6)$$

ulus of elasticity in bending, MPa (psi),
ort span, mm (in.),
n of beam tested, mm (in.),
a of beam tested, mm (in.), and
e of the tangent to the initial straight-line portion
e load-deflection curve, N/mm (lbf/in.) of deflec-

ear deflections can seriously reduce the apparent modulus
tropic composites when they are tested at low span-to-
For this reason, a span-to-depth ratio of 60 to 1 is
or flexural modulus determinations on these composites.
h should be determined on a separate set of replicate
ower span-to-depth ratio that induces tensile failure in the
he beam along its lower face. Since the flexural modulus
otropic laminates is a critical function of ply-stacking
l not necessarily correlate with tensile modulus, which is
quence dependent.

ant Modulus— The secant modulus is the ratio of
esponding strain at any selected point on the
curve, that is, the slope of the straight line that
in and a selected point on the actual stress-strain
be expressed in megapascals (pounds per square
lected point is chosen at a prespecified stress or
rdance with the appropriate material specification
er contract. It is calculated in accordance with Eq
m equal the slope of the secant to the load-
ve. The chosen stress or strain point used for the
n of the secant shall be reported.
ord Modulus (E_f)—The chord modulus may be
om two discrete points on the load deflection

TABLE 2 Flexural Modulus

Mean, 10^3 psi	Values Expressed in units of % of 10^3 psi			
	V_r[A]	V_R[B]	r[C]	R[D]
338	4.79	7.69	13.6	21.8
485	2.89	7.18	8.15	20.4
810	13.7	16.1	38.8	45.4
816	3.49	4.20	9.91	11.9
1790	5.52	5.52	15.6	15.6
1950	10.9	13.8	30.8	39.1

boratory coefficient of variation for the indicated material. It is pooling the within-laboratory standard deviations of the test f the participating laboratories: $Sr = [[(s_1)^2 + (s_2)^2 \ldots + (s_n)^2]/n]$ ivided by the overall average for the material) × 100.
-laboratory reproducibility, expressed as the coefficient of varia- $S_L^2)^{1/2}$ where S_L is the standard deviation of laboratory means. ivided by the overall average for the material) × 100.
oratory critical interval between two test results = 2.8 × V_r.
-laboratory critical interval between two test results = 2.8 × V_R.

curve. The selected points are to be chosen at two prespecified stress or strain points in accordance with the appropriate material specification or by customer contract. The chosen stress or strain points used for the determination of the chord modulus shall be reported. Calculate the chord modulus, E_f using the following equation:

$$E_f = (\sigma_{f2} - \sigma_{f1})/(\epsilon_{f2} - \epsilon_{f1}) \quad (7)$$

where:

σ_{f2} and σ_{f1} are the flexural stresses, calculated from Eq 3 or Eq 4 and measured at the predefined points on the load deflection curve, and ϵ_{f2} and
ϵ_{f1} are the flexural strain values, calculated from Eq 5 and measured at the predetermined points on the load deflection curve.

12.10 *Arithmetic Mean*— For each series of tests, the arithmetic mean of all values obtained shall be calculated to three significant figures and reported as the "average value" for the particular property in question.

12.11 *Standard Deviation*—The standard deviation (estimated) shall be calculated as follows and be reported to two significant figures:

$$s = \sqrt{(\Sigma X^2 - nX^2)/(n-1)} \quad (8)$$

where:
s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

13. Report

13.1 Report the following information:

13.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history (for laminated materials, ply-stacking sequence shall be reported),

13.1.2 Direction of cutting and loading specimens, when appropriate,

13.1.3 Conditioning procedure,

13.1.4 Depth and width of specimen,

13.1.5 Procedure used (A or B),

13.1.6 Support span length,

13.1.7 Support span-to-depth ratio if different than 16:1,

13.1.8 Radius of supports and loading noses if different than 5 mm,

13.1.9 Rate of crosshead motion,

13.1.10 Flexural strain at any given stress, average value and standard deviation,

13.1.11 If a specimen is rejected, reason(s) for rejection,

13.1.12 Tangent, secant, or chord modulus in bending, average value, standard deviation, and the strain level(s) used if secant or chord modulus,

13.1.13 Flexural strength (if desired), average value, and standard deviation,

13.1.14 Stress at any given strain up to and including 5 % (if desired), with strain used, average value, and standard deviation,

13.1.15 Flexural stress at break (if desired), average value,

ard deviation,

Type of behavior, whether yielding or rupture, or other observations, occurring within the 5 % strain

Date of specific version of test used.

ision and Bias [8]

bles 1 and 2 are based on a round-robin test in 1984, in accordance with Practice E 691, involv- aterials tested by six laboratories using Procedure A. material, all the specimens were prepared at one ach "test result" was the average of five individual tions. Each laboratory obtained two test results for rial.

—Caution: The following explanations of *r* and *R* (14.2- ntended only to present a meaningful way of considering the precision of these test methods. The data given in Tables 2 d not be applied rigorously to the acceptance or rejection of s those data are specific to the round robin and may not be ve of other lots, conditions, materials, or laboratories. Users of ethods should apply the principles outlined in Practice E 691 data specific to their laboratory and materials, or between specific laboratories. The principles of 14.2-14.2.3 would then be valid for such data.

14.2 *Concept of "r" and "R" in* Tables 1 and 2—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing five specimens for each test result, then:

14.2.1 *Repeatability*— Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the *r* value for that material. *r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

14.2.2 *Reproducibility*— Two test results obtained by different laboratories shall be judged not equivalent if they differ by more than the *R* value for that material. *R* is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

14.2.3 The judgments in 14.2.1 and 14.2.2 will have an approximately 95 % (0.95) probability of being correct.

14.3 *Bias*—No statement may be made about the bias of these test methods, as there is no standard reference material or reference test method that is applicable.

15. Keywords

15.1 flexural properties; plastics; stiffness; strength

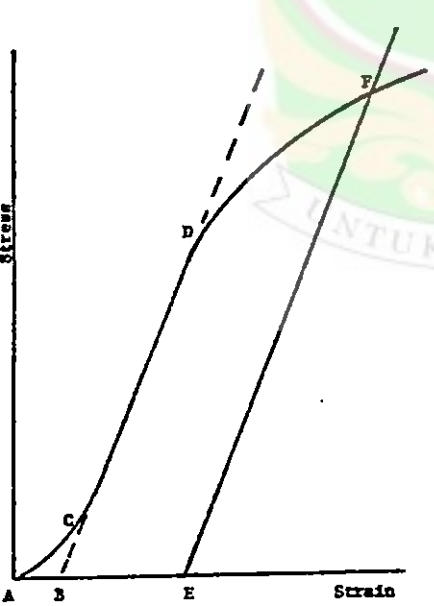
ng data are available from ASTM Headquarters. Request RR:

ANNEXES

(Mandatory Information)

A1. TOE COMPENSATION

n a typical stress-strain curve (see Fig. A1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.



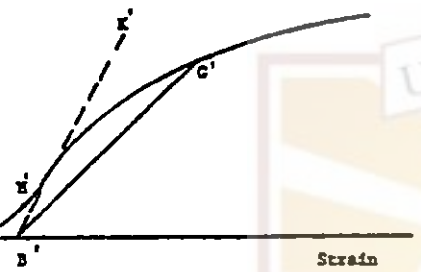
-Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (see Fig. A1.1), a continuation of the linear *(CD)* region of the curve is constructed through the zero-stress axis. This intersection *(B)* is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset *(BE)*, if applicable. The elastic modulus can be determined by dividing the stress at any point along the Line *CD* (or its extension) by the strain at the same point (measured from Point *B*, defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (see Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection Point *H'*. This is extended to intersect the strain axis at Point *B'*, the corrected zero-strain point. Using Point *B'* as zero strain, the stress at any point *(G')* on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B' G'*). For those materials with no linear region, any attempt to use the tangent through

yield point may result in unacceptable error.



me chart recorders plot the mirror image of this graph.
G. A1.2 Material with No Hookean Region

n point as a basis for determination of an offset

A2. MEASURING AND SETTING SPAN

flexural fixtures that have adjustable spans, it is at the span between the supports is maintained he actual measured span is used in the calculation dulus, and strain, and the loading nose or noses are nd aligned properly with respect to the supports. e steps as follows can improve the repeatability of when using these adjustable span fixtures.

easurement of Span:

his technique is needed to ensure that the correct n estimated span, is used in the calculation of

cribe a permanent line or mark at the exact center ort where the specimen makes complete contact. mark depends on whether the supports are fixed or e Figs. A2.1 and A2.2).

sing a vernier caliper with pointed tips that is at least 0.1 mm (0.004 in.), measure the distance supports, and use this measurement of span in the

FIG. A2.1 Markings on Fixed Specimen Supports

FIG. A2.2 Markings on Rotatable Specimen Supports

A2.3 *Setting the Span and Alignment of Loading Nose(s)*—To ensure a consistent day-to-day setup of the span and ensure the alignment and proper positioning of the loading nose, simple jigs should be manufactured for each of the standard setups used. An example of a jig found to be useful is shown in Fig. A2.3.

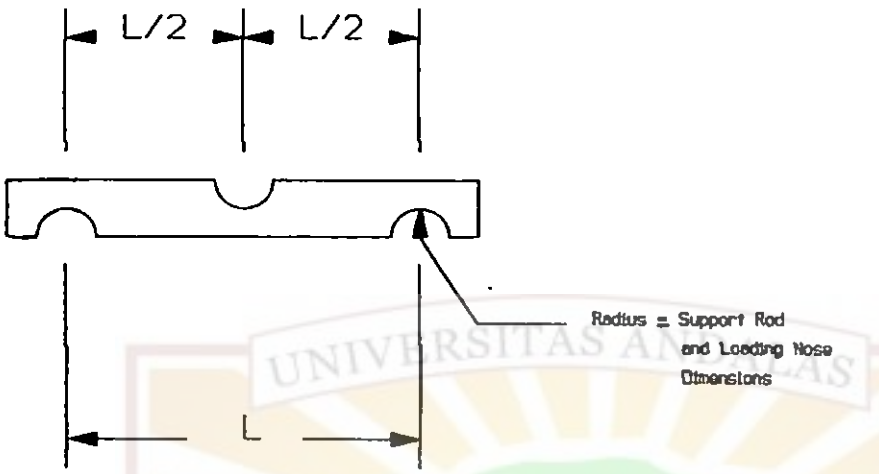


FIG. A2.3 Fixture Used to Set Loading Nose and Support Spacing and Alignment

SUMMARY OF CHANGES

This section identifies the location of selected changes to these test methods. For the convenience of the user, Committee D20 has highlighted those changes that may impact the use of these test methods. This section may also include descriptions of the changes or reasons for the changes, or both.

2:
ed 9.1 and 9.2.
0:
ed 12.1.
9:
ed 10.1.3.

D 790 – 98:
(*1*) Section 4.2 was rewritten extensively to bring this standard closer to ISO 178.
(*2*) Fig. 2 was added to clarify flexural behaviors that may be observed and to define what yielding and breaking behaviors look like, as well as the appropriate place to select these points on the stress strain curve.

Lampiran 3. Pengukuran dan Perhitungan Kuat Lentur

a) Tanpa Penguburan

Kode sampel	P (N)	l (mm)	B (mm)	H (mm)	fr (N/mm^2)
Tanpa gelatin	11,120	103	15,20	5,1	4,346
	77,844	103	14,50	4,9	34,546
	76,064	103	14,70	4,8	34,698
Rata-rata					24,530
Penambahan 5 g	28,913	103	15,00	6,7	6,634
	30,248	103	13,50	6,6	7,947
	31,657	103	15,00	6,7	7,264
Rata-rata					7,282
Penambahan 10 g	44,482	103	14,10	7,4	8,901
	53,321	103	14,50	7,5	10,100
	42,134	103	15,60	7,3	7,831
Rata-rata					8,944
Penambahan 15 g	59,606	103	16,40	6,3	14,148
	59,598	103	16,50	6,5	13,208
	63,065	103	16,70	6,2	15,178
Rata-rata					14,178

b) Penguburan 10 Hari

Kode sampel	P (N)	l (mm)	B (mm)	H (mm)	fr (N/mm^2)
Tanpa gelatin	28,913	103	14,9	4,4	15,486
	73,395	103	14,6	5,7	23,905
	79,178	103	14,5	4,6	39,870
Rata-rata					26,420
Penambahan 5 g	65,054	103	15,3	5,2	24,294
	70,726	103	15,7	5,5	23,008
	70,038	103	15,7	5,6	21,978
Rata-rata					23,093
Penambahan 10 g	75,987	103	14,7	5,9	22,943
	77,844	103	14,5	6,3	20,898
	67,014	103	13,7	6,3	19,041
Rata-rata					20,961
Penambahan 15 g	data tidak dapat diambil				
Rata-rata					

c) Penguburan 20 Hari

Kode sampel	P (N)	l (mm)	B (mm)	H (mm)	fr (N/mm^2)
Tanpa gelatin	70,726	103	14,5	5,3	26,828
	8,007	103	15	5,4	2,828
	70,726	103	14,5	5,3	26,828
Rata-rata					18,828
Penambahan 5 g	87,185	103	14,5	6,7	20,694
	77,844	103	16,1	5,9	21,460
	62,275	103	14,4	5,7	20,565
Rata-rata					20,906
Penambahan 10 g	79,178	103	15,7	6,9	16,366
	85,850	103	15,1	6,7	19,568
	82,514	103	15,4	6,8	17,903
Rata-rata					17,945
Penambahan 15 g					
Rata-rata	data tidak dapat diambil				

d) Penguburan 30 hari

Kode sampel	P (N)	l (mm)	B (mm)	H (mm)	fr (N/mm^2)
Tanpa gelatin	88,964	103	14,9	5	36,899
	74,730	103	14,5	4,1	47,368
	27,112	43	14,3	5,1	11,262
Rata-rata					31,843
Penambahan 5 g	54,713	103	15,5	6,8	11,794
	77,844	103	15	6,9	16,841
	31,582	103	15,9	6,8	6,637
Rata-rata					11,757
Penambahan 10 g	66,543	103	15,5	7,2	12,795
	90,298	103	16	7,2	16,820
	44,482	103	15,1	7,2	8,780
Rata-rata					12,798
Penambahan 15 g					
Rata-rata	data tidak dapat diambil				

e) Penguburan 40 Hari

Kode sampel	P (N)	l (mm)	B (mm)	H (mm)	fr (N/mm^2)
Tanpa gelatin	37,365	103	14,6	5,6	12,609
	36,030	103	14,2	5,3	13,956
	26,244	103	14,5	4,8	12,137
Rata-rata					12,900
Penambahan 5 g	32,497	103	15,2	6,6	7,583
	26,554	103	17	5,2	8,925
	73,395	103	15,8	6,7	15,988
Rata-rata					10,832
Penambahan 10 g	68,057	103	15,8	6,9	13,978
	39,106	103	15,1	6,5	8,994
	53,231	103	15,9	6,7	11,522
Rata-rata					11,498
Penambahan 15 g	data tidak dapat diambil				
Rata-rata					

Perhitungan Kuat Lentur

$$fr = \frac{3\,P\,l}{2\,B\,H^2}$$

$$fr = \frac{3\,(77{,}844)(103)}{2\,(14{,}5)(4{,}9)^2}$$

$$fr = \frac{23928{,}96}{696{,}29}$$

$$fr = 34{,}546\ N/mm^2$$

Lampiran 4. Pengukuran dan Perhitungan Kuat Tarik

Kode Sampel	Gaya (N)	Lebar (mm)	Tebal (mm)	A (mm^2)	σ (N/mm^2)	Lo (mm)	ΔL (mm)	e	ME (N/mm^2)
B1	94,302	20,3	3,4	69,020	1,366	165	1,346	0,008	167,488
B2	31,582	18,6	4,0	74,400	0,424	165	0,330	0,002	212,245
B3	120,546	15,6	4,6	71,760	1,680	165	2,159	0,013	128,381
			Rata-rata		1,157				169,371
C1	27,579	13,5	6,4	86,400	0,319	165	0,483	0,003	109,044
C2	120,546	13,1	4,7	61,570	1,958	165	0,279	0,002	1157,880
C3	109,426	17,6	5,4	95,040	1,151	165	0,762	0,005	249,312
			Rata-rata		1,143				505,412
D1	56,937	17,1	6,1	104,310	0,546	165	0,813	0,005	110,780
D2	56,937	17,1	6,1	104,310	0,546	165	0,813	0,005	110,780
D3	56,937	17,1	6,1	104,310	0,546	165	0,813	0,005	110,780
			Rata-rata		0,546				110,780
E1	79,178	14,0	5,0	70,000	1,131	165	0,533	0,003	350,157
E2	52,489	13,5	5,1	68,850	0,762	165	3,607	0,022	34,874
E3	77,844	13,6	6,4	87,040	0,894	165	0,356	0,002	414,515
			Rata-rata		0,929				266,515

Tegangan Mekanis

$$\sigma = \frac{F}{A}$$

$$\sigma = \frac{94,302}{69,02} = 1,366 \text{ N/mm}^2$$

Regangan

$$\varepsilon = \frac{\Delta L}{L}$$

$$\varepsilon = \frac{1,346}{165} = 0,008$$

Modulus Elastisitas

$$E = \frac{\sigma}{\varepsilon}$$

$$E = \frac{1{,}366}{0{,}008} = 167{,}488\ \text{N/mm}^2$$

Lampiran 5. Bentuk Sampel Uji Tarik